Environmental radioactivity in Denmark in 1979

Aarkrog, A.; Bøtter-Jensen, Lars; Dahlgaard, Henning; Hansen, Heinz Johs. Max; Lippert, Jørgen Emil; Nielsen, Sven Poul; Nilsson, Karen

Publication date:
1980

Document Version
Publisher's PDF, also known as Version of record

Risø-R-421

Risø-R-421

RISØ

Risø-R-421

Environmental Radioactivity in Denmark in 1979

A. Aarkrog, L. Bøtter-Jensen, H. Dahlgaard, Heinz Hansen, J. Lippert, S. P. Nielsen and Karen Nilsson

Risø National Laboratory, DK-4000 Roskilde, Denmark
June 1980

Risø-R-421

ENVIRONMENTAL RADIOACTIVITY IN DENMARK IN 1979

A. Aarkrog, L. Bøtter-Jensen, H. Dahlgaard, Heinz Hansen,
J. Lippert, S.P. Nielsen and Karen Nilsson

Abstract. Strontium-90 was determined in samples from all over the country of precipitation, ground water, lake and stream water, drinking water, sea water, dried milk, grain, bread, potatoes, vegetables, fruit, total diet, and human bone. Furthermore, ^{90}Sr was determined in local samples of air, rain water, grass, sea plants, fish, and meat. Cesium-137 was determined in sea water, sediments, milk, grain products, potatoes, vegetables, fruit, total diet, sea plants, fish, and meat. Estimates of the mean contents of radiostrontium and radiocesium in the human diet in Denmark during 1979 are given. Tritium was determined in precipitation, ground water and sea water. Plutonium and americium were measured in sediments and sea plants. The γ-background was measured regularly by TLD, ionization chamber and on site γ-spectroscopy at locations around Risø, at ten of the State experimental farms along the coasts of the Great Belt and around Gyllingnæs. The marine environments at Barsebäck and Ringhals were monitored for ^{137}Cs and corrosion products (^{58}Co, ^{60}Co, ^{65}Zn, ^{54}Mn). Finally the report includes routine surveys of environmental samples from the Risø area.

UDC 614.73(489)

June 1980
Risø National Laboratory

ISBN 87-550-0686-8
ISSN 0106-2840
ISSN 0106-407X

Risø Repro 1980

CONTENTS

ABBREVIATIONS AND UNITS

J: joule: the unit of energy; 1 J = 1 Nm (= 0.239 cal)
Gy: gray: the unit of absorbed dose = 1 J kg^{-1} (= 100 rad)
Sv: sievert: the unit of dose equivalent = 1 J kg^{-1} (= 100 rem)
Bq: becquerel: the unit of radioactivity = 1 s^{-1} (= 27 pCi)

cal: calorie = 4.186 J
rad: 0.01 Gy
rem: 0.01 Sv
Ci: curie: $3.7 \cdot 10^{10}$ Bq (= $2.22 \cdot 10^{12}$ dpm)

T: tera: 10^{12}
G: giga: 10^{9}
M: mega: 10^{6}
m: milli: 10^{-3}
μ: mikro: 10^{-6}
n: nano: 10^{-9}
p: pico: 10^{-12}
f: femto: 10^{-15}
a: atto: 10^{-18}

cap.: caput: (per individual)
TNT: trinitrotoluol; 1 Mt TNT: nuclear explosives equivalent to 10^{9} kg TNT.

cpm: counts per minut
dpm: disintegrations per minut
OR: observed ratio
CF: concentration factor
FP: fission products
μR: micro-roentgen, 10^{-6} roentgen
S.U.: pCi ^{90}Sr (g Ca)$^{-1}$
O.R.: observed ratio
M.U.: pCi ^{137}Cs (g K)$^{-1}$

V: vertebrae

m: male

f: female

nSr: natural (stable) Sr

eqv. mg KCl: equivalents mg KCl: activity as from 1 mg KCl (~0.88 dpm)

S.D.: standard deviation: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{(n-1)}}$

S.E.: standard error: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{n(n-1)}}$

U.C.L.: upper control level

L.C.L.: lower control level

Δ: one standard deviation due to counting

S.S.D.: sum of squares of deviation: $\Sigma(\bar{x}-x_i)^2$

f: degrees of freedom

s^2: variance

v^2: ratio between the variance in question and the residual variance

P: probability fractile of the distribution in question

η: coefficient of variation, relative standard deviation

ANOVA: analysis of variance

A: relative standard deviation 20-33%

B: relative standard deviation >33%, such results are not considered significantly different from zero activity

B.D.L.: below detection limit

In the significance test the following symbols were used:

* : probably significant (P > 95%)

** : significant (P > 99%)

***: highly significant (P > 99.9%)

Samples:

H: sea water

J: soil

L: air

B: bed soil

Å: eel

PG: grass

PH: sea plants
D: drain water
S: waste water
R: precipitation
M: milk

1. INTRODUCTION

1.1.

The present report is the twenty-third of a series of periodic reports(cf. ref. 1) dealing with measurements of radioactivity in Denmark. The organization of the material in the present report corresponds to that of last years report. After the introduction and a chapter on organization and facilities there follows a chapter on environmental monitoring around nuclear facilities (Risø, Barsebäck and Ringhals). Chapter four deals with fallout nuclides in the abiotic environment, i.e., air, water and soil. Chapters five and six comprise fallout nuclides in the human diet and human tissues, respectively. Chapter seven is devoted to environmental tritium studies. Plutonium and americium in environmental samples are treated in chapter eight, and external radiation in chapter nine. The names of the authors of each chapter appear at its head.

The Becquerel has been introduced along with the Curie in tables and figures. In the tables it has been accomplished by doubling all tables. In the figures we have used the right-hand ordinate for Becquerel. In the tables with Becquerels all units have to be changed to the SI system, i.e. litres become m^3, g becomes kg, km^2 becomes m^2, and years, months and days become seconds.

1.2.

The methods of radiochemical analysis[2-4] and the statistical treatment of the results [12] are still based on the principles established in previous reports[1].

1.3.

The report does not include detailed tables of the total β-measurements originating from the environmental control of the Risø site. These tables are available in the form of micro-cards at the Risø library.

1.4.

The report contains no information on sample collection and analysis except in cases where these procedures have been altered.

1.5.

In 1979 the personnel of the Environmental Control Section of the Health Physics Department consisted of two chemists, one biologist, eight laboratory technicians, two sample collectors, and two laboratory assistants. The Section for Electronics Development continued to give assistance with the maintenance of counting equipment, with the interpretation of γ-spectra and with data treatment. The program (cf. 2) used in the calculations of ^{90}Sr and the γ-analysis, as well as the program for data treatment, were developed by this Section.

1.6.

The composition of the average Danish diet used in this report is identical with that proposed in 1962 by Professor E. Hoff-Jørgensen, Ph.D.

2. FACILITIES[1,6,7,8]

By J. Lippert

2.1. Detectors

The activity of the samples is measured as follows:

Alpha (^{239}Pu, ^{241}Am): 16 solid-state surface barrier detectors connected to four multichannel analyzers (64 channels per detector).

Beta (^{90}Y mainly): 5 low-level gas-flow Geiger counters, 4 of them provided with automatic sample chambers. Three new "multi-detector"-systems each containing 5 sample counters and a common anticoincidence shield are now put into regular use. This type of detector is intended to replace the mechanical sample changers after a test period.

Gamma (natural and fallout isotopes): 5 Ge(Li) detectors in 10 cm lead shields and connected to five 1024-channel analyzers. One further Ge(Li) detector mounted on a tripod and a 4096-channel analyzer are used for field measurements, and a 8" x 4" NaI(Tl) in an underground shielded room is used for whole-body counting. Two of the Ge(Li) detectors have been replaced by new ones with higher efficiency.

2.2. Data treatment

Measured spectra are evaluated directly on a desk-top calculator or transferred to a Burroughs B6700 computer.

A program system STATDATA[16] is developed for registration and treatment of environmental measurements including multichannel analyzer spectra. To date, approximately 45 000 sets of results have been registered covering the period from 1957.

3. ENVIRONMENTAL MONITORING AT RISØ, BARSEBÄCK AND RINGHALS IN 1979

by H. Dahlgaard

3.1. Gross β-activity at Risø

3.1.1. Sea water

Fig. 3.1.1.1 shows the sample locations in Roskilde Fjord. The yearly mean for H I in 1979 was 61 eqv. mg KCl $(2.5\ g)^{-1}$ (in 1978: 59), for H III-VI: 58 eqv. mg KCl $(2.5\ g)^{-1}$ (in 1978: 60) and for H VII-X: 59 eqv. mg KCl $(2.5\ g)^{-1}$ (in 1978: 59). Fig. 3.1.1.2 shows the mean levels of radioactivity in sea salt since 1957.

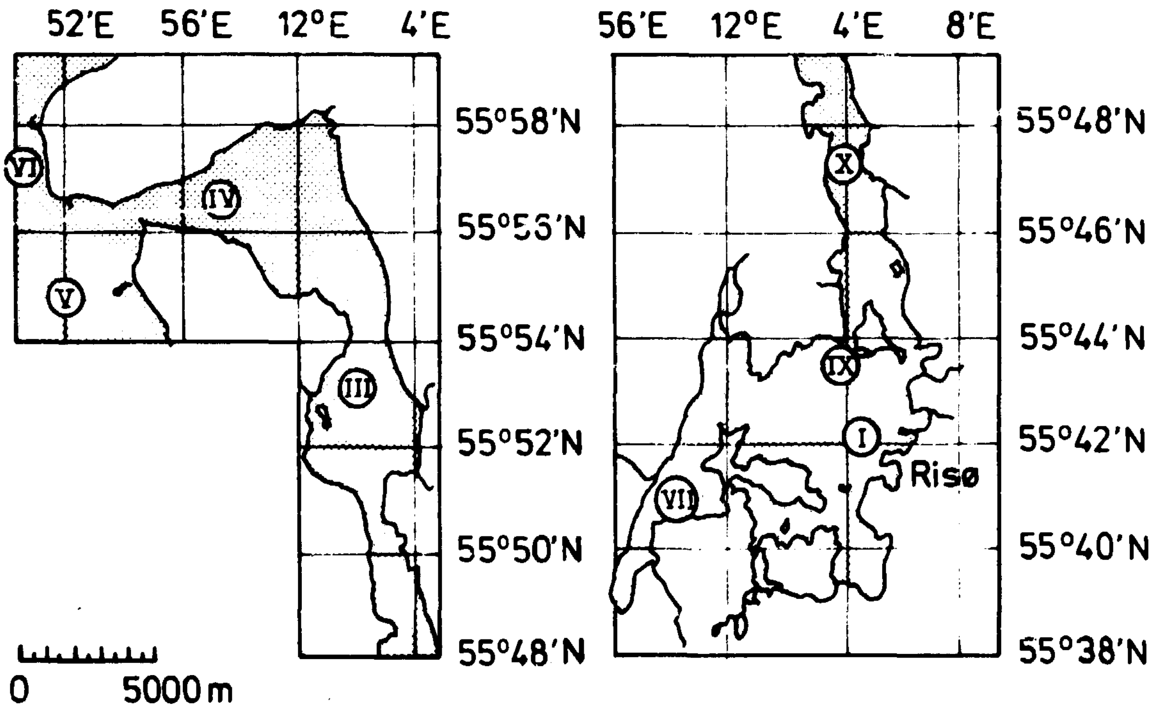


Fig. 3.1.1.1. Roskilde Fjord.

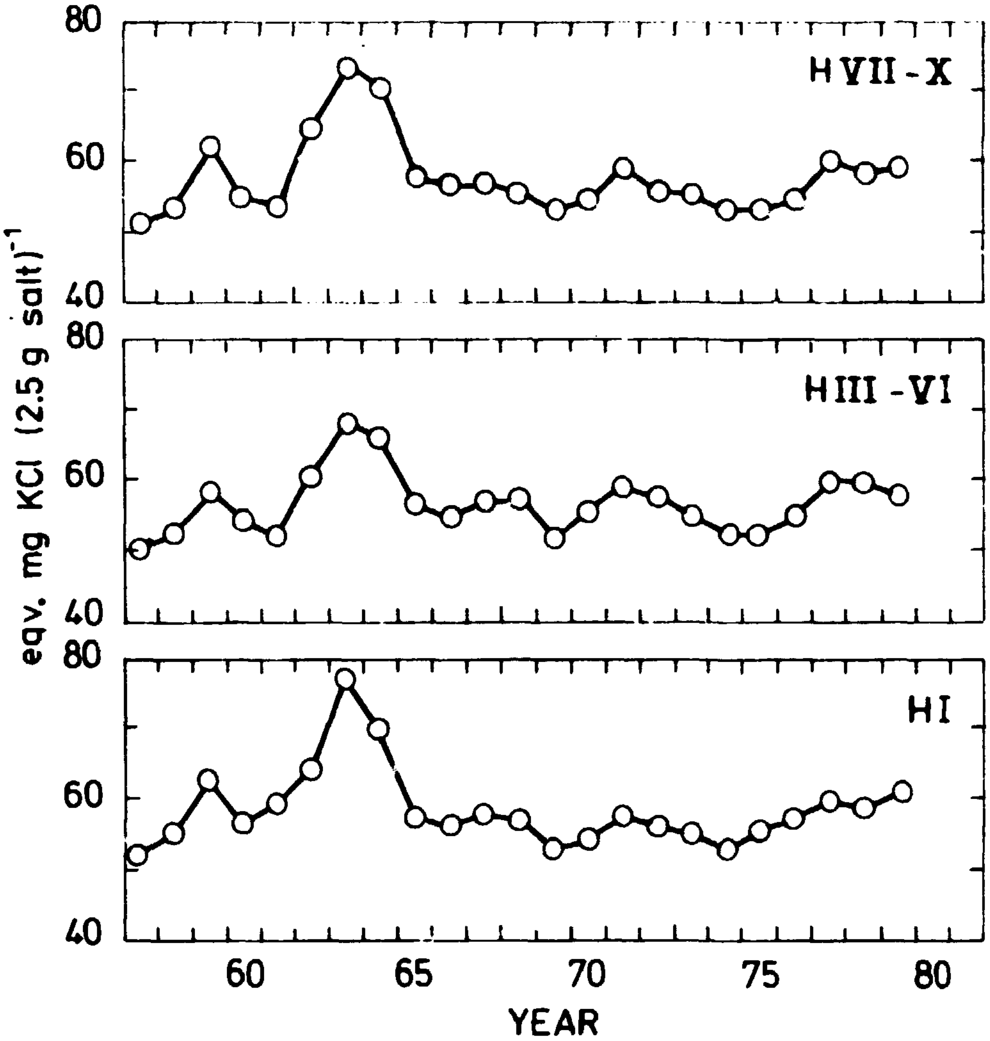


Fig. 3.1.1.2. Mean radioactivity in sea water 1957-1979.

3.1.2. Soil

No soil samples from the environment of Risø were measured for total β-activity in 1979.

3.1.3. Air

The mean value for the year was 0.08 eqv. mg KCl m^{-3} as compared with 0.18 eqv. mg KCl m^{-3} in 1978.

Fig. 3.1.3.1 shows the mean FP levels in air since 1957.

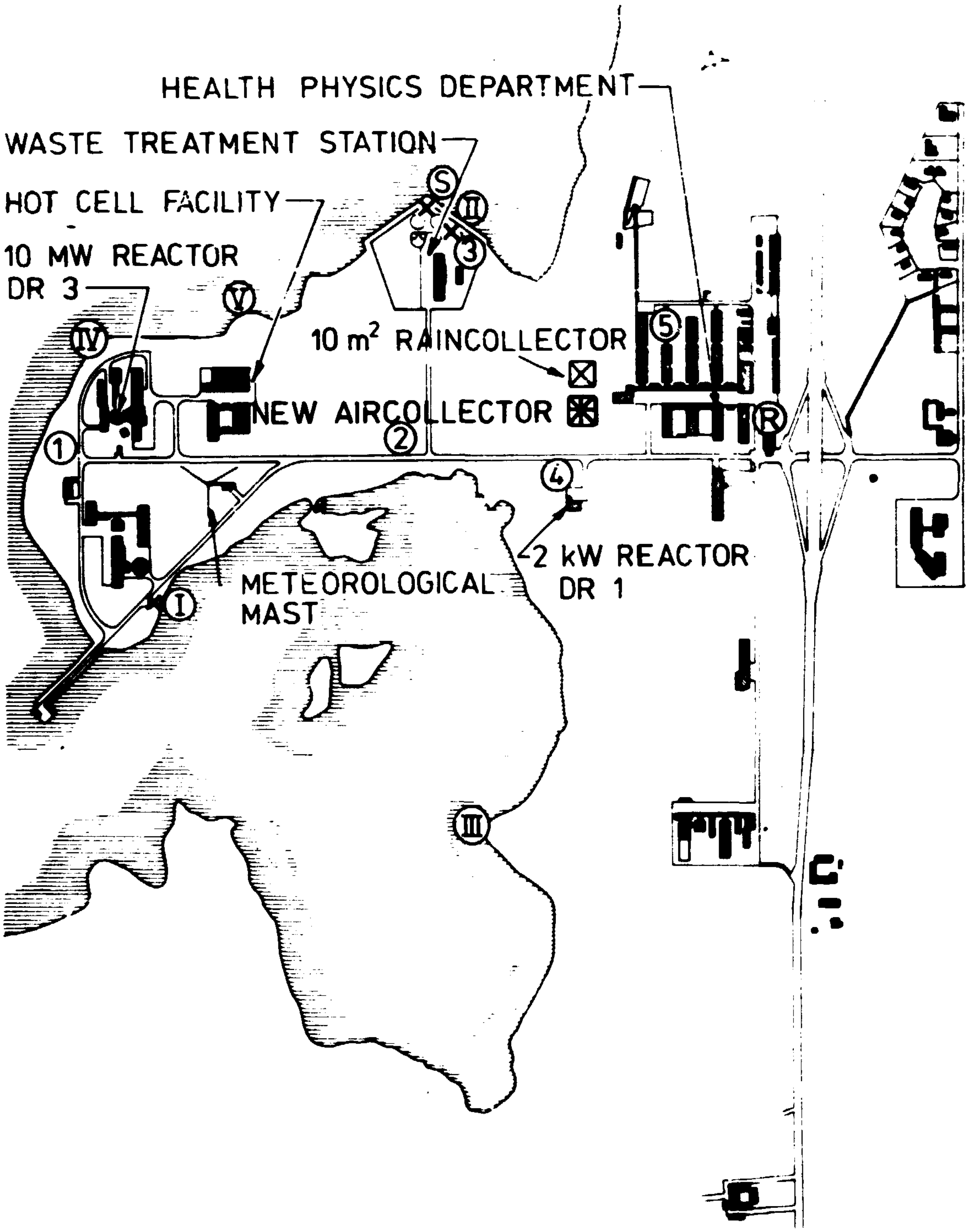


Fig. 3.1.2.1. Samling locations at Risø National Laboratory. 1-5: locations for rain bottles (0.03 m^2 each), ion exchange columns (0.06 m^2 each) and grass samples. I-V: sampling locations for draining water. S: sewage water. R: 1 m^2 daily rain collector. ☒ : 10 m^2 monthly ion exchange rain collector. ⊡ : new air collector.

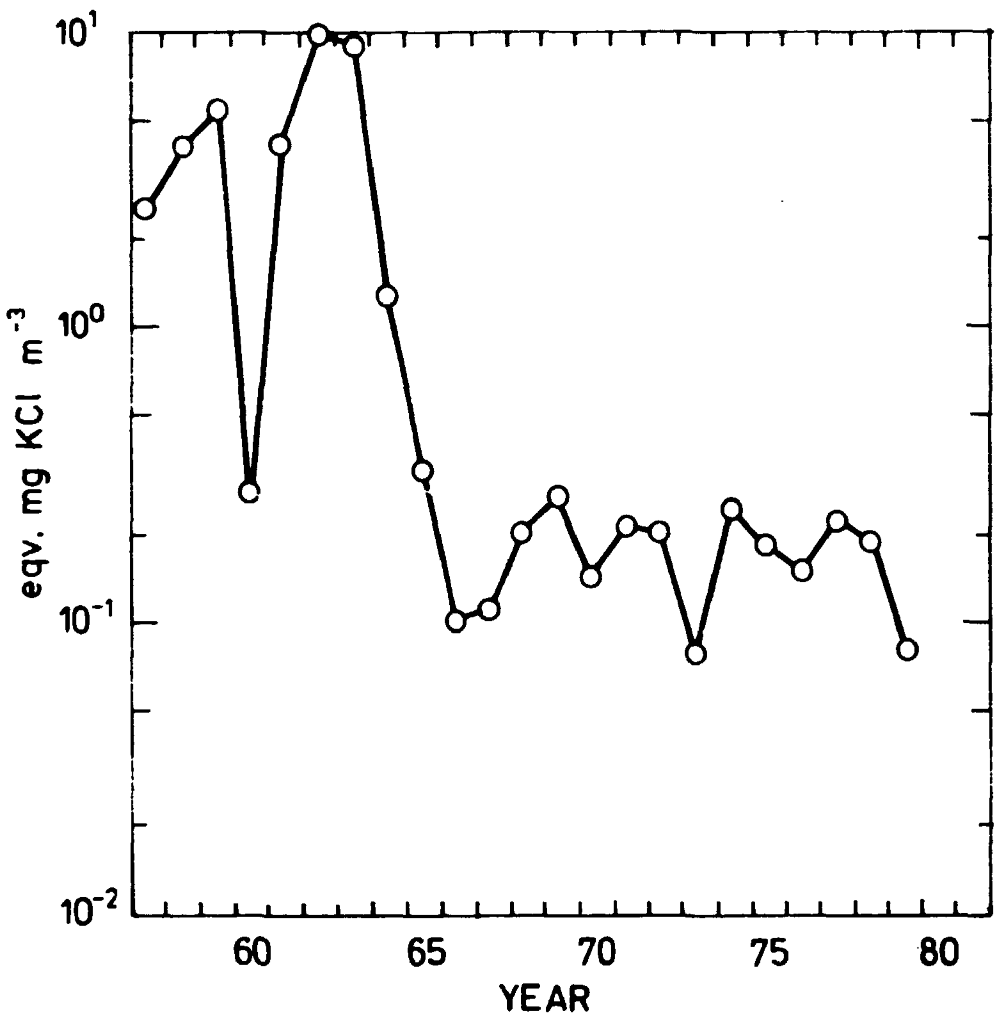


Fig. 3.1.3.1. Mean radioactivity in air, 1957-1979.

3.1.4. Sediment samples from Roskilde Fiord

The mean activity in sediment B I was 162 eqv. mg KCl (3.0 g ash)$^{-1}$ in 1979 as compared with 164 eqv. mg KCl (3.0 g)$^{-1}$ in 1978. Fig. 3.1.4.1 shows the mean levels for B I since 1957 (cf. also 3.4).

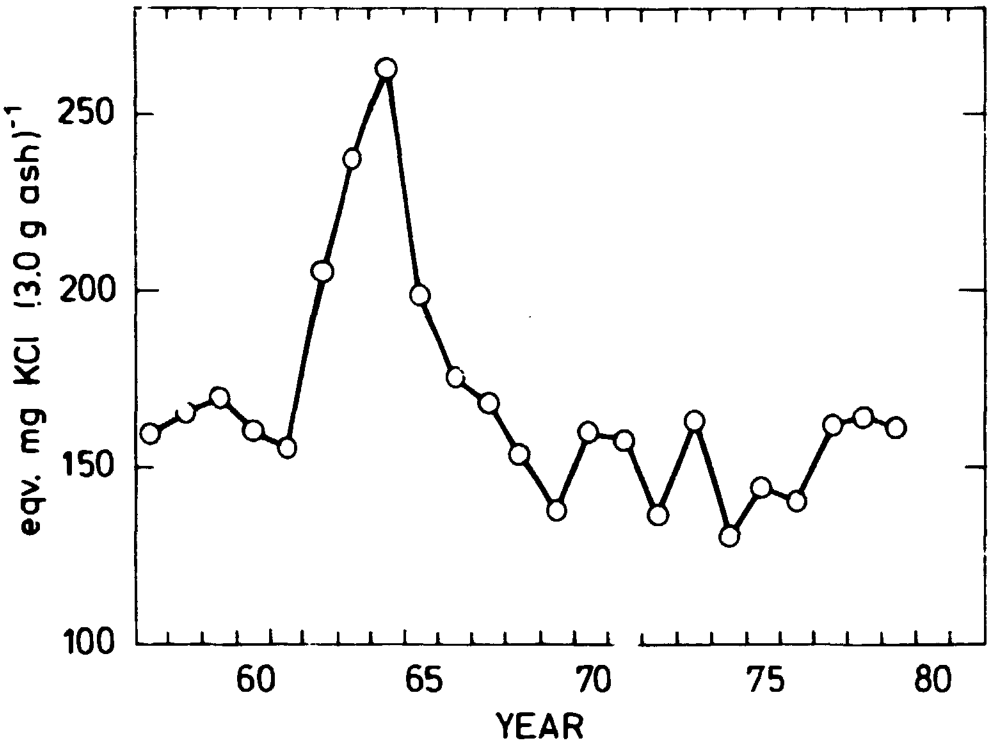


Fig. 3.1.4.1. Mean radioactivity in sediment samples (BI), 1957-1979.

3.1.5. Fish

No fish samples from Roskilde Fjord were measured for total β-avtivity in 1979.

3.1.6. Grass

The mean values were in 1979 for PG I: 7.5 eqv. mg KCl (0.1 g grass ash)$^{-1}$ (in 1978: 18). Fig. 3.1.6.1 shows the mean activities in grass ash since 1957.

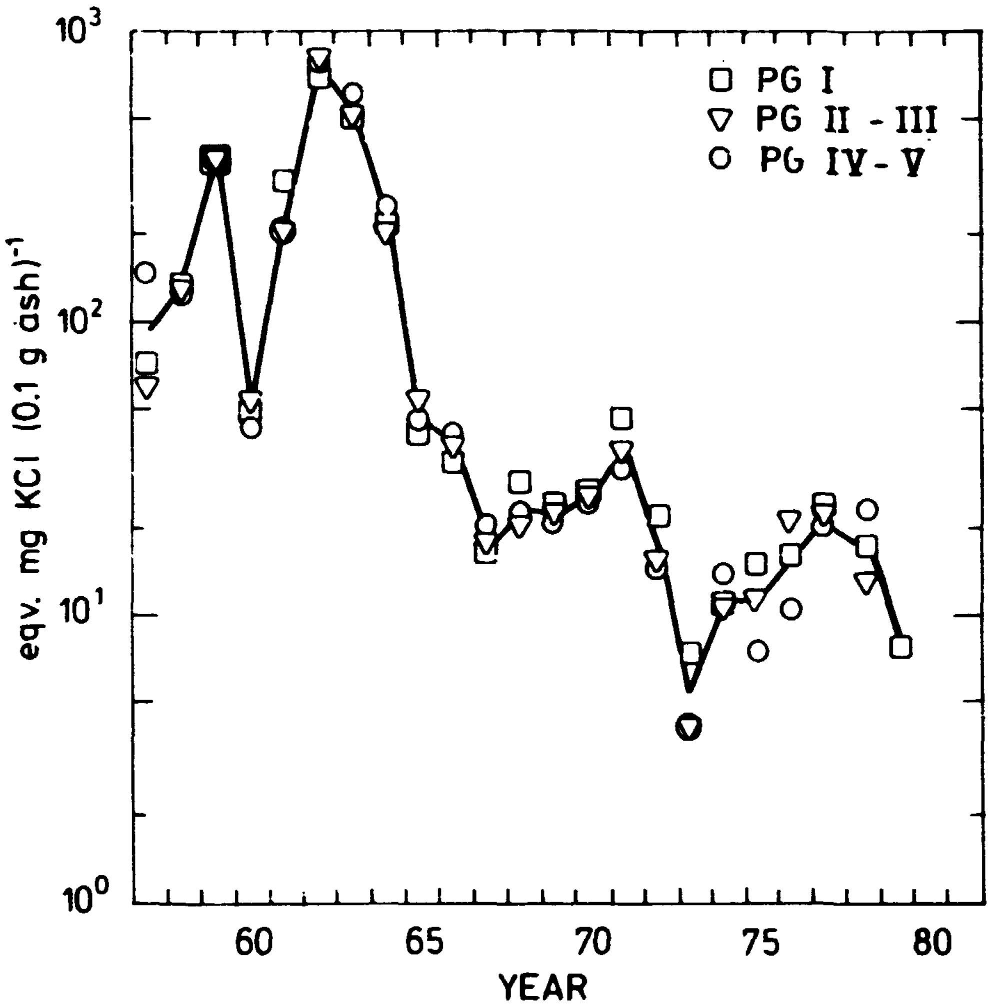


Fig. 3.1.6.1. Mean FP-radioactivity in grass ash, 1957-1979.

3.1.7. Sea plants

The mean FP level in 1979 in Fucus vesiculosus (PH I) was below the detection limit (1 in 1978). FP in Zostera marina (PH III-IX) was in 1979 below detection limit.

3.1.8. Fresh water

Fig. 3.1.8.1 shows the control chart for S (cf. fig. 3.1.2.1). The yearly means for D I, D II, D IV, and S in 1979 were 18 eqv. mg KCl l^{-1} (1978: 26), 15 eqv. mg KCl l^{-1} (1978: 19), 60 eqv. mg KCl l^{-1} (1978: 60), and 45 eqv. mg KCl l^{-1} (1978: 41) respectively. Fig. 3.1.8.2 shows the activity in drainage water (D) and waste water (S).

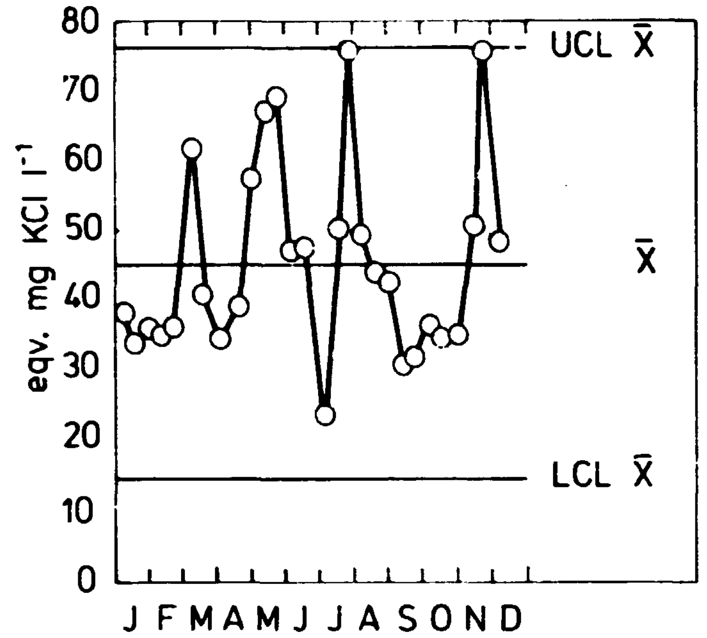


Fig. 3.1.8.1. Control chart for waste water (S) 1979.

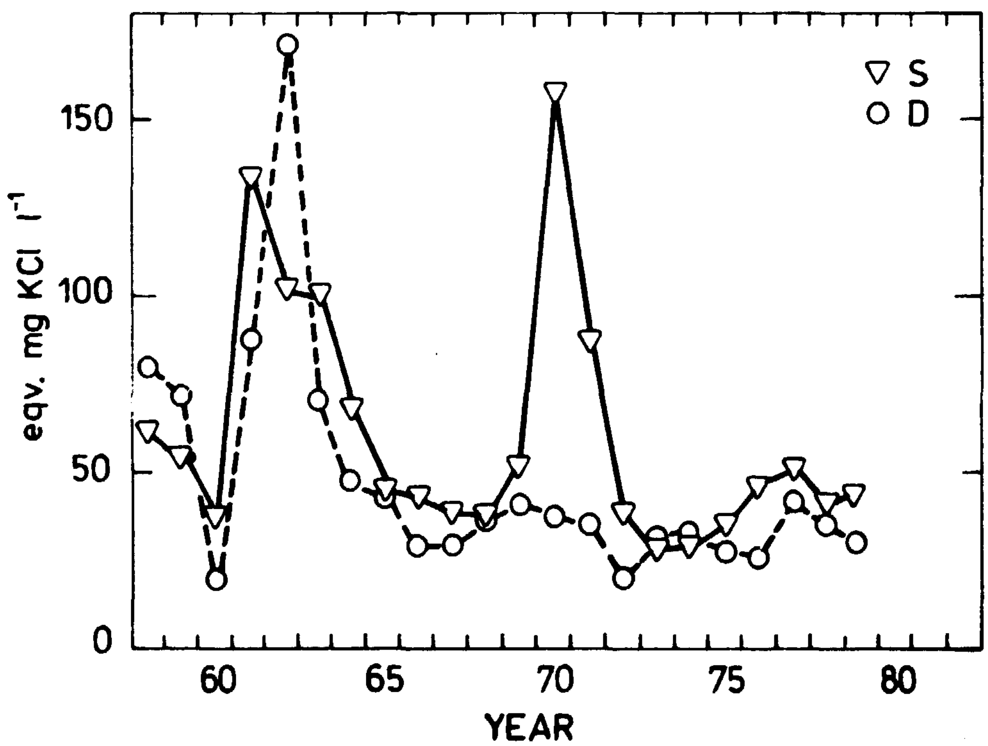


Fig. 3.1.8.2. Annual total-β mean levels in waste water (S) and drain water (D) collected at Risø 1958-1979.

3.1.9. Rain water

The total fallout in 1979 was measured at $9.5 \cdot 10^3$ eqv. mg KCl m^{-2}, and the annual mean concentration in rain water at Risø was 18 eqv. mg KCl l^{-1}. In 1978 the corresponding figures were $0.021 \cdot 10^6$ and 40 respectively.

Fig. 3.1.9.1 shows the specific activity in rain water since 1957.

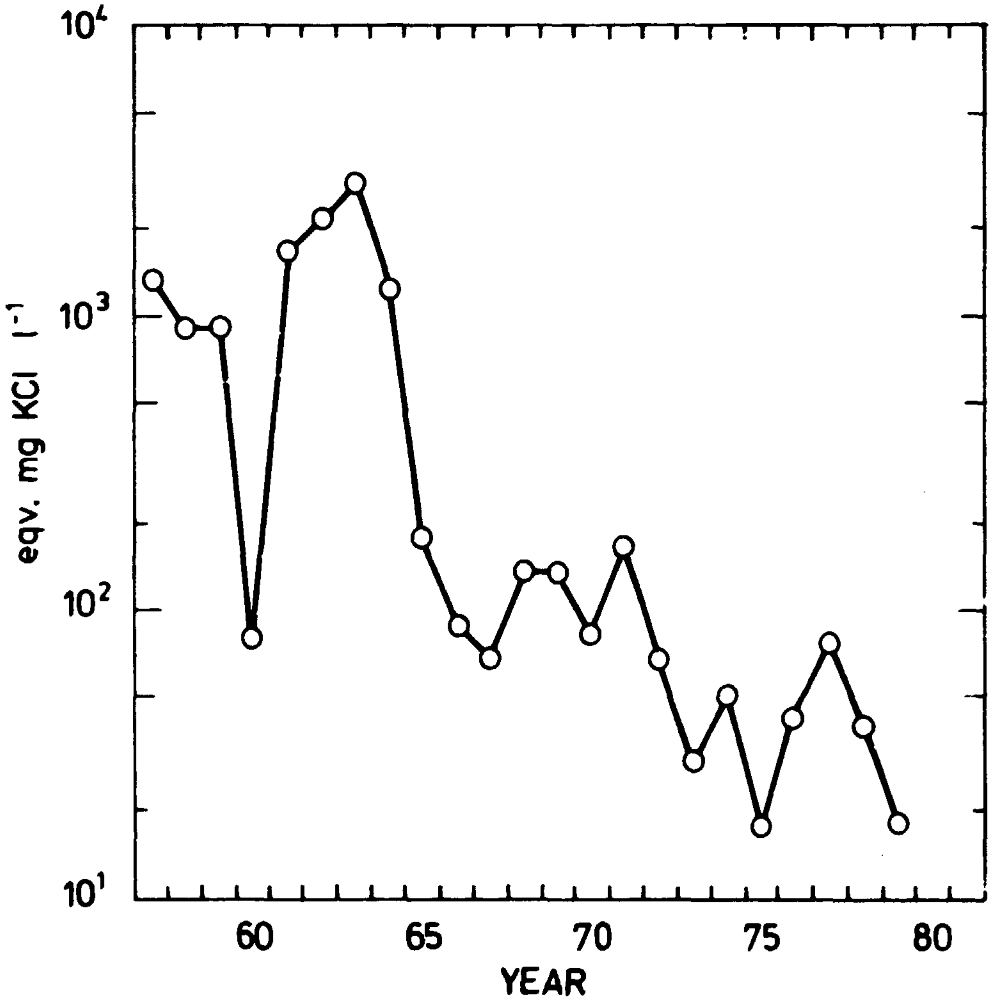


Fig. 3.1.9.1. Specific activity in precipitation, 1957-1979.

3.2. Marine environmental monitoring at Barsebäck and Ringhals

The radiological monitoring of the marine environment around the two nuclear power plants at Barsebäck and Ringhals in Sweden[1)] was continued in 1979.

Figures 3.2.1.1, 3.2.1.2 and 3.2.1.3 show the sampling locations.

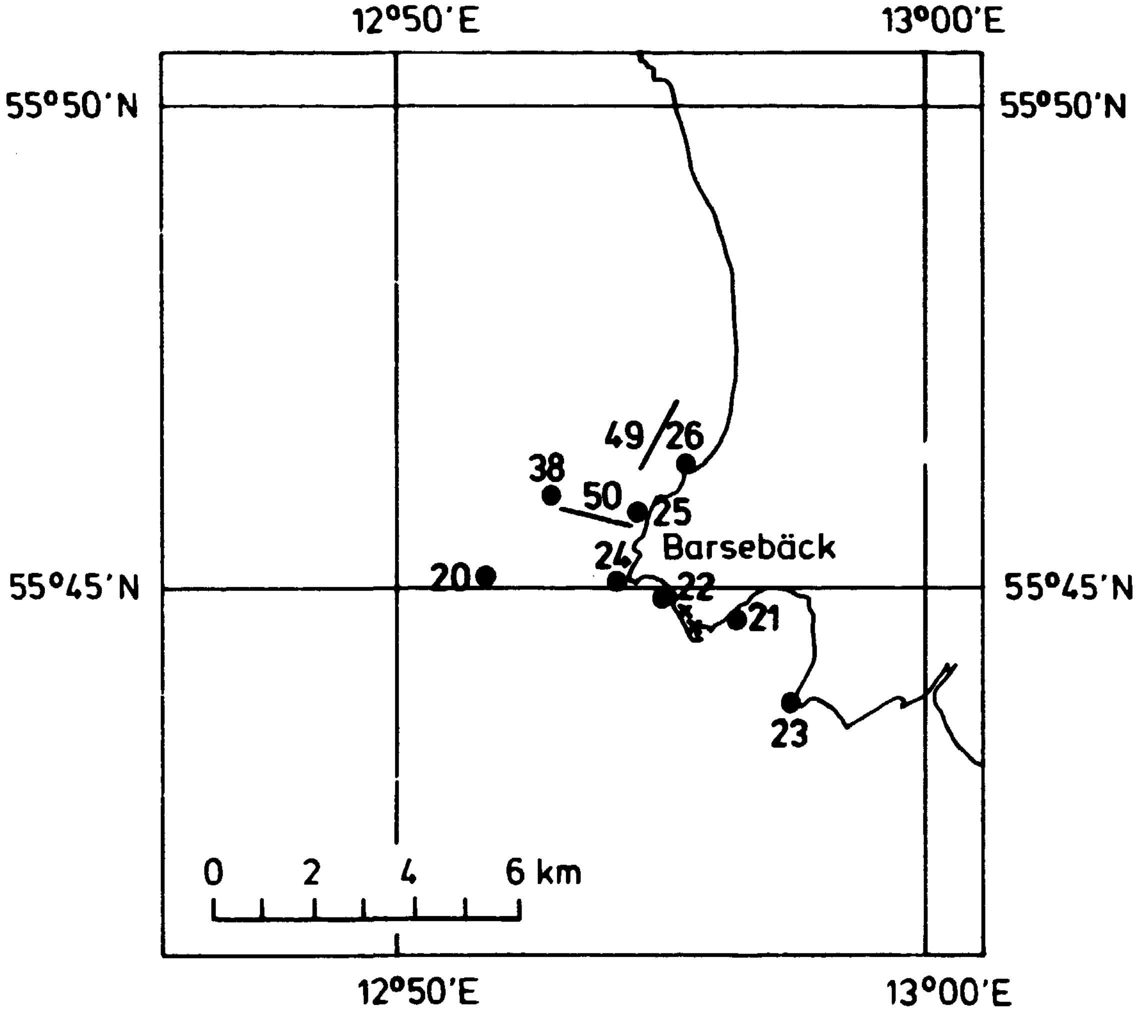


Fig. 3.2.1.1. Sampling locations at Barsebäck in 1979.
49 and 50 indicate fishing tracks.

This programme is sponsored by Nordic Liaison Committee for Atomic Energy (Nordisk kontaktorgan for atomenergi) as part of a co-operative activity together with the Department of Radiation Physics, University of Lund, Sweden.

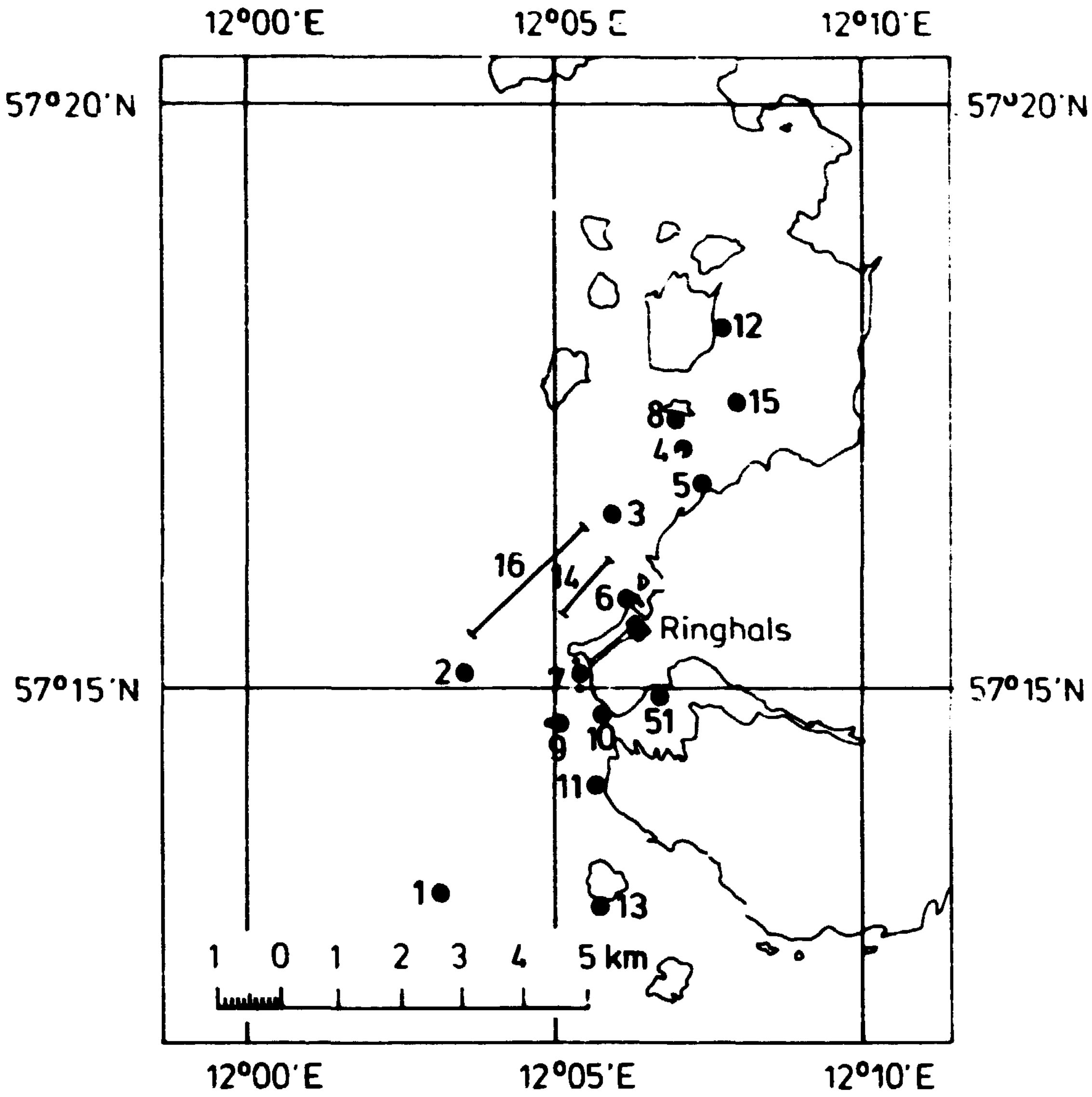


Fig. 3.2.1.2. Sampling locations at Ringhals. 14 and 16 indicate fishing tracks.

3.2.1. γ-emitting radionuclides in brown algae

Tables 3.2.1.1, 3.2.1.2 and 3.2.1.3 show the radionuclide concentrations found by γ-spectrometric analysis in brown algae sampled near Barsebäck and Ringhals in 1979. Table 3.2.1.4 shows results from the Sound (Øresund) further away from Barsebäck.

As noted in the 1977 and 1978 reports[1)] the concentration of the reactor-produced nuclides ^{60}Co, ^{58}Co, ^{54}Mn, ^{65}Zn and ^{110m}Ag decreases with distance from the outlet in a similar manner.

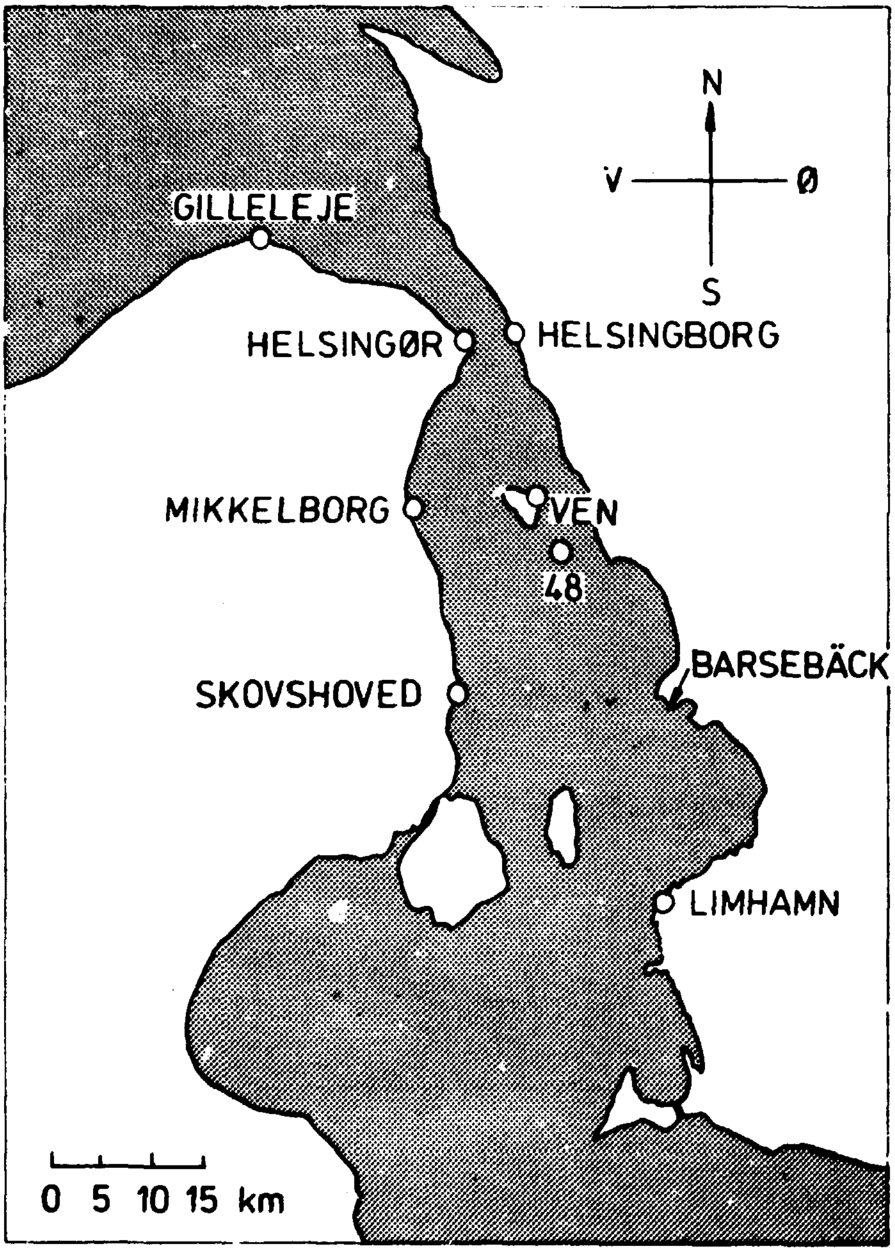


Fig. 3.2.1.3. Sampling locations in the Sound.

The decrease in concentration 125 km along the Swedish west coast north of the Barsebäck outlet has been described by a power function: $A = k\ X^{-1.4 \pm 0.1}$, where A is the activity concentration in Fucus and X is the distance in km[32,17].

Some of these data, e.g. Helsingborg, apparently differ from this power function, but data are too sparse to see any changes. However, the long-distance data from Øresund (Table 3.2.1.4)

Table 3.2.1.1.A. Gamma-emitting radionuclides in Fucus vesiculosus collected at Barsebäck in 1979 (Unit: pCi kg^{-1} fresh weight)

Date of sampling	6 April			19 June						7 January 1980	
Station** No.	24	21*	23*	22	24	25	26	21*	23*	24	23*
Weight fresh/dry	4.40	3.26	4.08	5.60	5.52	4.68	5.13	4.85	5.39	7.14	4.52
Distance from outlet in km	1.4	1.5	2.8	0.6	1.4	2.9	4.0	1.5	2.8	1.4	2.8
^{60}Co	25,100	2,530	1,470	9,140	9,270	2,080	1,520	1,730	505	8,530	431
^{58}Co	2,050	184	118	685	464	111	75	78	55	705	31
^{54}Mn	716	103	55 A	708	386	86	54	65	31	373	25
^{65}Zn	4,270	490	282	1,380	1,410	327	230	240	78	1,680	84
^{110m}Ag	122			88	62 A					28	
^{51}Cr	1,080			188 B							
^{137}Cs		71	90			60	60	70	81	49	71

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.1.

Table 3.2.1.1.B. Gamma-emitting radionuclides in Fucus vesiculosus collected at Barsebäck in 1979 (Unit: Bq kg^{-1} fresh weight)

Date of sampling	6 April			19 June						7 January 1980	
Station** No.	24	21*	23*	22	24	25	26	21*	23*	24	23*
Weight fresh/dry	4.40	3.26	4.08	5.60	5.52	4.68	5.13	4.85	5.39	7.14	4.52
Distance from outlet in km	1.4	1.5	2.8	0.6	1.4	2.9	4.0	1.5	2.8	1.4	2.8
^{60}Co	0.93×10^3	94	54	0.34×10^3	0.34×10^3	77	56	64	18.7	0.32×10^3	15.9
^{58}Co	76	6.8	4.4	25	17.2	4.1	2.8	2.9	2.0	26	1.15
^{54}Mn	26	3.8	2.0 A	26	14.3	3.2	2.0	2.4	1.15	13.8	0.92
^{65}Zn	158	18.1	10.4	51	52	12.1	8.5	8.9	2.9	62	3.1
^{110m}Ag	4.5			3.3	2.3					1.04	
^{51}Cr	40			7.0 B							
^{137}Cs		2.6	3.3			2.2	2.2	2.6	3.0	1.81	2.6

** Locations south of the outlet; the other locations were situated north of the outlet.*

***Cf. Fig. 3.2.1.*

Table 3.2.1.2.A. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.), Ascophyllum nodosum (As.no.) and Fucus serratus (Fu.se.) collected at Ringhals may 12 and 13, 1979. (Unit: pCi kg^{-1} fresh weight)

Station No.**	7	7	6	5	8	12	9*	11*	13*	13*	37*
Weight fresh/dry	4.40	5.63	3.64	3.91	3.32	4.65	4.13	4.25	3.85	4.64	3.71
Species	Fu.ve.	As.no.	Fu.se.	Fu.se.	Fu.se.	Fu.ve.	Fu.se.	Fu.se.	Fu.se.	Fu.ve.	Fu.se.
Distance from outlet in km	0.2	0.2	1.9	4.1	4.8	6.3	1.1	1.9	4.1	4.1	19.4
^{60}Co	712	846	398	200	175	53	404	320	70	34	19.8
^{58}Co	603	99	135	88	61	24 A	246	68	21		
^{54}Mn	112	18 A	38	17 A	20 A	8.8 B	35	20 A	11 A		7 B
^{65}Zn	1409	1039	682	407	268	75	805	916	187	71 A	
^{137}Cs						66			74	58	62
^{110m}Ag	98	100	48	28 A	18 A		52	43			

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.2.

Table 3.2.1.2.B. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.). Ascophyllum nodosum (As.no.) and Fucus serratus (Fu.se.) collected at Ringhals may 12 and 13, 1979. (Unit: Bq kg^{-1} fresh weight)

Station No.**	7	7	6	5	8	12	9*	11*	13*	13*	37*
Weight fresh/dry	4.40	5.63	3.64	3.91	3.32	4.65	4.13	4.25	3.85	4.64	3.71
Species	Fu.ve.	As.no.	Fu.se.	Fu.se.	Fu.se.	Fu.ve.	Fu.se.	Fu.se.	Fu.se.	Fu.ve.	Fu.se.
Distance from outlet in km	0.2	0.2	1.9	4.1	4.8	6.3	1.1	1.9	4.1	4.1	19.4
^{60}Co	26	31	14.7	7.4	6.5	1.96	14.9	11.8	2.6	1.26	0.73
^{58}Co	22	3.7	5.0	3.3	2.3	0.89 A	9.1	2.5	0.78		
^{54}Mn	4.1	0.67 A	1.41	0.63 A	0.74 A	0.33 B	1.30	0.74 A	0.41 A		0.26 B
^{65}Zn	52	38	25	15.1	9.9	2.8	30	34	6.9	2.6	
^{137}Cs						2.4			2.7	2.1	2.3
^{110m}Ag	3.6	3.7	1.78	1.04 A	0.67 A		1.92	1.59			

** Locations south of the outlet; the other locations were situated north of the outlet.*

***Cf. Fig. 3.2.2.*

Table 3.2.1.3.A. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.), Fucus serratus (Fu.se.) and Ascophyllum nodosum (As.no.) collected at Ringhals November 15, 1979. (Unit: pCi kg^{-1} fresh weight)

Station No.**	7	7	8	8	8	12	9*	13*
Weight fresh/dry	4.57	4.16	4.42	4.23	3.64	3.94	4.56	4.34
Species	Fu.ve.	Fu.se.	Fu.ve.	Fu.se.	As.no.	Fu.ve.	Fu.ve.	Fu.se.
Distance from outlet in km	0.2	0.2	4.8	4.8	4.8	6.3	1.1	4.1
^{60}Co	2,260	2,560	140	157	66	102	202	171
^{58}Co	690	820	45	48	15.0		70	66
^{54}Mn	520	380	33	27		20 B	44	21 A
^{65}Zn	26,700	36,100	2050	1230	764	793	3280	1470
^{137}Cs	135	101				101		84
^{110m}Ag	270	320	22 A	13 B	24		27	
^{134}Cs	30 A	27 A						

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.2.

Table 3.2.1.3.B. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.), Fucus serratus (Fu.se.) and Ascophyllum nodosum (As.no.) collected at Ringhals November 15, 1979. (Unit: Bq kg^{-1} fresh weight)

Station No.**	7	7	8	8	8	12	9*	13*
Weight fresh/dry	4.57	4.16	4.42	4.23	3.64	3.94	4.56	4.34
Species	Fu.ve.	Fu.se.	Fu.ve.	Fu.se.	As.no.	Fu.ve.	Fu.ve.	Fu.Se.
Distance from outlet in km	0.2	0.2	4.8	4.8	4.8	6.3	1.1	4.1
^{60}Co	84	95	5.2	5.8	2.4	3.8	7.5	6.3
^{58}Co	26	30	1.66	1.78	0.56		2.6	2.4
^{54}Mn	19.2	14.1	1.22	1.00		0.74 B	1.63	0.78 A
^{65}Zn	0.99×10^3	1.34×10^3	76	46	28	29	0.121×10^3	54
^{137}Cs	5.0	3.7				3.7		3.1
^{110m}Ag	10.0	11.8	0.81 A	0.48 B	0.89		1.00	
^{134}Cs	1.11 A	1.00 A						

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.2.

indicate that only a minor fraction of the activity reaches the Danish coast, and that the main part of the plume from Barsebäck remains near the Swedish west coast.

If the decrease in activity with distance from Ringhals is also described by a power function, $A = kX^{-\beta}$, the β-value for the May 79-sampling is 0.68 northwards till 6.3 km and 0.86 south-

Table 3.2.1.4.A. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) collected in the Sound in 1979. (Unit: pCi kg^{-1} fresh weight)

Date of sampling	9 April	7 April		19 April		19 June		7 January 1980	
Location*	Skovshoved havn	Ven	Mikkelborg	Helsingør	Gilleleje	Skovshoved havn	Helsingborg	Helsingør	Limhamn
Weight fresh/dry	4.74	3.82	6.34	5.83	7.49	5.50	6.12	6.33	4.49
Distance from outlet in km	20.0	22.4	30.2	39.6	60.2	20.0	39.0	39.6	17.8
Species	Fu.se.	Fu.ve.	Fu.ve.	Fu.se.	Fu.ve.	Fu.ve.	Fu.ve.	Fu.se.	Fu.ve.
^{60}Co	79	82	15.9	31.4	4.2		29.7	16.5	21.8
^{54}Mn	9.0 A							4.0 A	
^{137}Cs	58	40	59	40	35	60	55	51	69
^{131}I	71 A								
^{58}Co		11.0 B							
^{65}Zn								10.2 A	

*Cf. Fig. 3.2.1.3.

Table 3.2.1.4.B. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) collected in the Sound in 1979. (Unit: Bq kg^{-1} fresh weight)

Date of sampling	9 April	7 April		19 April		19 June		7 January 1980	
Location*	Skovshoved havn	Ven	Mikkelborg	Helsingør	Gilleleje	Skovshoved havn	Helsingborg	Helsingør	Limhamn
Weight fresh/dry	4.74	3.82	6.34	5.83	7.49	5.50	6.12	6.33	4.49
Distance from outlet in km	20.0	22.4	30.2	39.6	60.2	20.0	39.0	39.6	17.8
Species	Fu.se.	Fu.ve.	Fu.ve.	Fu.se.	Fu.ve.	Fu.ve.	Fu.ve.	Fu.se.	Fu.ve.
^{60}Co	2.9	3.0	0.59	1.16	0.16		1.10	0.61	0.81
^{54}Mn	0.33 A							0.15 A	
^{137}Cs	2.1	1.48	2.2	1.48	1.30	2.2	2.0	1.89	2.6
^{131}I	2.6 A								
^{58}Co		0.41 B							
^{65}Zn								0.38 A	

Cf. Fig. 3.2.1.3.

wards till 4.1 km. A pooling of the results from 1977-79 yields β-values of 0.79±0.04 (SE, n = 5) and 0.93±0.05 (SE, n = 4) northwards and southwards, respectively.

Part of the ^{54}Mn-activity is believed to originate from sources other than Ringhals and Barsebäck - probably fallout - as ^{54}Mn to ^{60}Co ratios tend to be higher at distant locations.

The nuclides ^{131}I, ^{137}Cs and ^{134}Cs show no decrease with distance from the outlet. Part of the radiocesium activity originates from Ringhals, but the "background" level in the Kattegat, from fallout and from Windscale discharges, is so high (cf. 4.4) that this is of minor importance. The $^{134}Cs/^{137}Cs$ ratio may indicate a 35% rise in the ^{137}Cs level due to Ringhals discharges directly in the plume (location 7). The short-lived ^{131}I probably originates from hospital or laboratory discharges, as no fresh fallout was detected in 1979 (cf. 4.1.3).

The intention to sample Fucus vesiculosus alone was not fulfilled. This led to a comparison of the 3 fucoids Fucus vesiculosus, Fucus serratus, and Ascophyllum nodosum. Although none of the ratios in Table 3.2.1.5 is significantly different from unity some trends may be noted. Compared with Fucus vesiculosus, Ascophyllum tends to show a lower concentration of ^{58}Co, ^{54}Mn

Table 3.2.1.5. Ratios of activity concentrations on fresh weight basis in Fucus vesiculosus (Fu.ve.), Fucus serratus (Fu.se.) and Ascophyllum nodosum (As.no.) collected at Ringhals 1978 and 1979

Isotope	Fu.ve./Fu.se.		Fu.ve./As.no.	
^{60}Co	0.7 ±0.1	(n=4)	1.2±0.5	(n=3)
^{58}Co	0.92±0.04	(n=3)	3.6±1.3	(n=3)
^{54}Mn	1.1 ±0.2	(n=3)	2.3	(n=1)
^{65}Zn	1.1 ±0.3	(n=2)	1.8±0.5	(n=3)
^{110m}Ag	1.0 ±0.2	(n=2)	1.2±0.2	(n=2)
^{137}Cs	1.1 ±0.3	(n=2)		
^{131}I	1.0	(n=1)	0.8	(n=1)
^{95}Zr	1.1	(n=1)		

The error term was 1 S.E.

and ^{65}Zn, whereas Fucus serratus is similar. The $^{60}Co/^{58}Co$-ratio tends to increase in the order Fucus vesiculosus < Fucus serratus < Ascophyllum nodosum, meaning that the "integration time" rises in the same manner. This may indicate the existence of differences in the mean age of the various species sampled.

Tables 3.2.1.6-3.2.1.8 report transfer factors calculated as

$$TF = \frac{A_i}{\frac{1}{m}\sum^{m} D_j} \text{ (pCi month kg}^{-1}\text{ mCi}^{-1}\text{) or (Bq kg}^{-1}\text{ s Bq}^{-1}\text{)},$$

and decay-corrected transfer factors calculated as

$$DTF_m = \frac{A_i}{\sum^{m} D_j e^{-\lambda(i-j)}} \text{ (pCi (m months) kg}^{-1}\text{ mCi}^{-1}\text{)},$$

where A_i is the activity of a sample collected in month i (pCi kg^{-1} fresh weight or Bq kg^{-1} fresh weight), D_j is the discharge during month j (mCi $month^{-1}$ or Bq s^{-1}), m is the number of months (or seconds) in the calculation and λ is the radioactive decay constant ($month^{-1}$). Monthly discharges are from reference 35. For the TF-calculations m is 12 months, whereas in the DTF-calculation m is chosen as the number of months for which DTF-values for ^{60}Co and ^{58}Co are equal. The "integration-time" is defined as this last m-value. If more months than the "integration time" are included in the calculation, DTF for ^{60}Co ($T_{½}$ ~ 1922 d) will be smaller than DTF for the relatively short-lived ^{58}Co ($T_{½}$ ~ 71.3 d), as also ^{60}Co-releases not included in the sample are included in the calculation, whereas the corresponding ^{58}Co discharges have decayed. Calculation of the "integration time" by DTF-values are made on the assumption that the algae cannot distinguish between the two isotopes, i.e. they are assumed to be in the same physicochemical state.

Values of the normal transfer factor TF and the decay-corrected transfer factor DTF from this investigation have been reported and discussed earlier[1,32,33].

In Tables 3.2.1.6 and 3.2.1.7 normal transfer factors, TF, from Barsebäck and Ringhals from 1979 and mean values from 1977-1978

Table 3.2.1.6.A. Transfer factor TF, without decay-correction. Fucus vesiculosus collected at Barsebäck, location 24, 1.4 km north of the outlet.

Isotope	Sampling date	Discharge the preceding 12 months		TF
		mCi month^{-1}	rel. S.D.%	pCi month kg^{-1} mCi^{-1}
^{60}Co	6/4-79	103.6	100	242
"	19/6-79	92.5	116	100
"	7/1-80	50.6	63	169
Mean	1979			170±41
	1978			122±65
	1977			168±46
^{58}Co	6/4-79	72.4	129	28.3
"	19/6-79	60.9	157	7.6
"	7/1-80	17.6	85	40.0
Mean	1979			25.3± 9.5
	1978			68 ±30
	1977			75 ±25
^{54}Mn	6/4-79	7.8	114	92
"	19/6-79	6.6	134	59
"	7/1-80	4.4	87	85
Mean	1979			79±10
	1978			77±27
	1977			133±25
^{65}Zn	6/4-79	20.1	120	213
"	19/6-79	19.0	129	74
"	7/1-80	12.3	64	137
Mean	1979			141±40
	1978			132±72
	1977			157±43
^{110m}Ag	6/4-79	6.8	88	17.9
"	19/6-79	5.9	103	10.5
"	7/1-80	1.94	60	14.4
Mean	1979			14.3± 2.1
	1978			16.4±11.7
	1977			14.7± 7.5
^{51}Cr	6/4-79	73	111	14.8
"	19/6-79	66	127	
"	7/1-80	39	31	
Mean	1979			14.8
	1978			1.5
	1977			5.6

The error term was ±1 S.E.

Table 3.2.1.6.B. Transfer factor, TF, without decay-correction. Fucus vesiculosus collected at Barsebäck, location 24, 1.4 km north of the outlet.

Isotope	Sampling date	Discharge the preceding 12 months		TF
		Bq s^{-1}	rel. S.D.%	Bq kg^{-1}s Bq^{-1}
^{60}Co	6/4-79	1460	100	0.64
"	19/6-79	1300	116	0.26
"	7/1-80	710	63	0.44
Mean	1979			0.45±0.11
	1978			0.32±0.17
	1977			0.44±0.12
^{58}Co	6/4-79	1020	129	0.074
"	19/6-79	860	157	0.020
"	7/1-80	250	85	0.105
Mean	1979			0.066±0.025
	1978			0.179±0.079
	1977			0.197±0.066
^{54}Mn	6/4-79	110	114	0.24
"	19/6-79	93	134	0.155
"	7/1-80	62	87	0.22
Mean	1979			0.20±0.03
	1978			0.20±0.07
	1977			0.35±0.07
^{65}Zn	6/4-79	280	120	0.56
"	19/6-79	270	129	0.195
"	7/1-80	173	64	0.36
Mean	1979			0.37±0.11
	1978			0.35±0.19
	1977			0.41±0.11
^{110m}Ag	6/4-79	96	88	0.047
"	19/6-79	83	103	0.028
"	7/1-80	27	60	0.038
Mean	1979			0.038±0.005
	1978			0.043±0.031
	1977			0.039±0.020
^{51}Cr	6/4-79	1030	111	0.039
"	19/6-79	930	127	
"	7/1-80	550	31	
Mean	1979			0.039
	1978			0.004
	1977			0.015

The error term was ±1 S.E.

Table 3.2.1.7.A. Transfer factor, TF, without decay-correction. Brown algae (from Tables 3.2.1.2.A and 3.2.1.3.A) collected at Ringhals, location 6, 1.9 km north of the outlet and location 9, 1.1 km south of the outlet.

Isotope	Sampling date	Discharge the preceding 12 months		TF pCi month kg^{-1} mCi^{-1}	
		mCi month^{-1}	rel. S.D.%	Location 6	Location 9
^{60}Co	12/5-79	166	77	2.40	2.44
"	15/11-79	119	50		1.69
Mean	1979			2.40	2.06±0.38
	1978			1.51±0.31	1.89±0.69
	1977			4.09±0.56	[illegible].90±0.90
^{58}Co	12/5-79	78	116	1.72	3.14
"	15/11-79	61	104		1.16
Mean	1979			1.72	2.15±0.99
	1978			0.85±0.38	1.70±0.76
	1977			1.21±0.67	2.50±1.02
^{54}Mn	12/5-79	16.6	99	2.06	1.87
"	15/11-79	11.8	68		3.75
Mean	1979			2.06	2.81±0.94
	1978			1.90±0.40	1.92±0.58
	1977			4.70±2.36	3.78±0.52
^{65}Zn	12/5-79	89	103	7.69	9.08
"	15/11-79	194	190		16.90
Mean	1979			7.69	13.0±3.9
	1978			4.54±0.08	10.6±5.1
	1977			12.9 ±7.9	22.7±10.2
^{110m}Ag	12/5-79	7.5	122	6.35	6.86
"	15/11-79	2.4	247		11.53
Mean	1979			6.35	9.2±2.3
	1978			4.80±0.22	5.01
	1977			45.8	49.0

The error term was ±1 S.E.

Table 3.2.1.7.8. Transfer factor, TF, without decay-correction. Brown algae (from Tables 3.2.1.2.8 and 3.2.1.3.8) collected at Ringhals, location 6, 1.9 km north of the outlet and location 9, 1.1 km south of the outlet.

Isotope	Sampling date	Discharge the preceding 12 months		TF Bq kg^{-1} s Bq^{-1}	
		Bq s^{-1}	rel. S.D.%	Location 6	Location 9
^{60}Co	12/5-79	2300	77	6.3×10^{-3}	6.4×10^{-3}
"	15/11-79	1670	50		4.4×10^{-3}
Mean	1979			6.3×10^{-3}	$(5.4\pm1.0)\times10^{-3}$
	1978			$(4.0\pm0.8)\times10^{-3}$	$(5.0\pm1.8)\times10^{-3}$
	1977			$(10.8\pm1.5)\times10^{-3}$	$(18.1\pm2.4)\times10^{-3}$
^{58}Co	12/5-79	1100	116	4.5×10^{-3}	8.3×10^{-3}
"	15/11-79	860	104		3.1×10^{-3}
Mean	1979			4.5×10^{-3}	$(5.7\pm2.6)\times10^{-3}$
	1978			$(2.2\pm1.0)\times10^{-3}$	$(4.5\pm2.9)\times10^{-3}$
	1977			$(3.2\pm1.8)\times10^{-3}$	$(6.6\pm2.7)\times10^{-3}$
^{54}Mn	12/5-79	260	99	5.4×10^{-3}	4.9×10^{-3}
"	15/11-79	166	68		9.9×10^{-3}
Mean	1979			5.4×10^{-3}	$(7.4\pm2.5)\times10^{-3}$
	1978			$(5.0\pm1.1)\times10^{-3}$	$(5.0\pm1.5)\times10^{-3}$
	1977			$(12.4\pm6.2)\times10^{-3}$	$(9.9\pm1.4)\times10^{-3}$
^{65}Zn	12/5-79	1250	103	20×10^{-3}	24×10^{-3}
"	15/11-79	2700	190		44×10^{-3}
Mean	1979			20×10^{-3}	$(34\pm10)\times10^{-3}$
	1978			$(11.9\pm0.2)\times10^{-3}$	$(28\pm13)\times10^{-3}$
	1977			$(34\pm21)\times10^{-3}$	$(60\pm27)\times10^{-3}$
^{110m}Ag	12/5-79	105	122	16.7×10^{-3}	18.0×10^{-3}
"	15/11-79	34	247		30×10^{-3}
Mean	1979			16.7×10^{-3}	$(24\pm6)\times10^{-3}$
	1978			$(12.6\pm0.6)\times10^{-3}$	13.2×10^{-3}
	1977			120×10^{-3}	129×10^{-3}

The error term was ±1 S.E.

are reported. These values can be extrapolated to other distances by the power-functions mentioned above. As the monthly discharges are very different the TF-values will vary even if the plants accumulate the same fraction of the discharged nuclides throughout the year. Differences in growth and perhaps in temperature also contribute to the variation. The fairly good reproducibility of the TF-values for most nuclides from both Barsebäck and Ringhals is there remarkable.

Although Fucus is not eaten, these TF-values show the transfer of radioisotopes to living organisms and the variation in this transfer with time and between different sites. Thus, a future change in TF-value for one or more nuclides indicates a change in the transfer of released activity to Fucus, and therefore probably to edible organisms as well. Such changes could, for instance, be due to changes in physicochemical form of the released nuclides, but TF-values can also be used to give an estimate of the magnitude of an uncontrolled accidental release.

A comparison of the TF-values from Barsebäck and Ringhals indicates that even if the values are calculated for the same distance, or transformed to the same distance, e.g. one km, by the power-functions established above, the TF-value for radio-cobalt, ^{54}Mn, and ^{65}Zn are much higher in the Barsebäck than in the Ringhals area, whereas ^{110m}Ag values is of the same order of magnitude. At Barsebäck transfer factors for discharged ^{110m}Ag is lower than for Co, Mn, and Zn nuclides, whereas at Ringhals it is higher. Also, at Barsebäck TF-values for ^{65}Zn is of the same order of magnitude as those for ^{60}Co and ^{54}Mn, whereas at Ringhals ^{65}Zn values are higher than those of ^{60}Co and ^{54}Mn. Thus, it is evident that differences between Barsebäck and Ringhals are limited not only to absolute values of the transfer factors (e.g. due to hydro-dynamical differences) but extend to ratios between different pairs of radionuclides. Even isotope-ratios of the same nuclide, namely $^{58}Co/^{60}Co$, tend to differ at the two sites. At Barsebäck the short-lived ^{58}Co ($T_{½}$ 71 d) shows a lower TF-value than the relatively long-lived ^{60}Co ($T_{½}$ 5.3 y), which is to be expected. However, at Ringhals the TF-values for ^{58}Co and ^{60}Co are sometimes similar. Furthermore, for most samples from Ringhals the DTF_m-values cannot be calculated as the $^{58}Co/^{60}Co$ ratio in the algae is too high compared with that of the discharge. This indicates that the two cobalt-isotopes may behave differently in the Ringhals environment.

These apparent differences, in accumulation of the various nuclides, between the two sites could be explained by differences between the environments. For instance, salinity is highest, approx. 20 o/oo, in the Ringhals area, whereas it is lower, averaging approx. 10 o/oo, in the Barsebäck area. However, a more reasonable explanation is that the radionuclides may be discharged in different physicochemical forms from the two plants due to differences in waste-water treatment. This might even explain the cobalt anomalies at Ringhals, as ^{58}Co and ^{60}Co are produced from stable Ni and Co, respectively. As a final possibility, differences in transfer factors at the two sites and between cobalt isotopes at Ringhals might be explained by faults in the discharge reports. As most of the differences seem to be reproducible this last possibility must be discounted.

Decay-corrected transfer factors calculated for the number of months, m, that make ^{60}Co and ^{58}Co values approximately equal, are reported in Table 3.2.1.8. "m" is denoted as the "integration time", which was described previously[1,32,33]. As the DTF-values are independent of the physical decay of the nuclides, they are supposed to show the transfer of the metals independently of the decay-constants: ideally, they are unaffected by oscillations in the rate of discharge.

The apparent seasonal oscillation in the 1978-data has not been completely reproduced in 1979 (Table 3.2.1.8). These calculations are to be continued for some years in an attempt to elucidate the nature of the variations.

As stated previously[1,32,33], the DTF-values indicate that the uptake and elimination of radiocobalt, ^{54}Mn and ^{65}Zn released from Barsebäck might be similar in Fucus vesiculosus. As mentioned above, this is not the case at Ringhals.

Table 3.2.1.8. Decay-corrected transfer factors, DTF. Fucus vesiculosus collected at Barsebäck, location 24, 1.4 km north of the outlet. (Unit: pCi (m months) kg^{-1} mCi^{-1})

Date of sampling	770615	771022	771206	780417	780615	780908*	781210	790406	790619	800107
m month	7.5	10.7	11.2	8	8	4	10	13	16	16
^{60}Co	28.0	20.6	19.8	3.33	8.13	22.5	29.9	20.6	7.1	9.2
^{58}Co	28.1	21.1	19.9	3.30	7.67	22.5	30.3	20.6	7.1	8.7
^{54}Mn	38.8	17.3	18.1	3.22	9.01	15.3	18.4	12.3	7.0	7.9
^{65}Zn	30.8	21.3	22.8	5.14	9.36	22.0	46.0	30.9	10.7	13.2
^{110m}Ag		3.90		0.66			3.74	2.53	1.45	1.08
^{51}Cr				0.77				10.6		

*Mean of 2 samples.

3.2.2. γ-emitting radionuclides in benthic invertebrates

In 1979, 2 mussel-samples from Barsebäck were analysed (Table 3.2.2.1). On the assumption that the activity ratios between Mytilus and Fucus established at Ringhals (Table 3.2.2.3) are

Table 3.2.2.1.A. Gamma-emitting radionuclides in Mytilus edulis collected at Barsebäck in 1979. (Unit: pCi kg^{-1} fresh weight)

Part	Date	Sampling location	Depth in m	^{137}Cs	^{60}Co	^{65}Zn
Soft part	6/4	20	10	9.3	4.6 A	
Shells	"	"	"		14.7	
Soft part	9/4	49	7	11.6	26.4	18.6 A
Shells	"	"	"		110	

Table 3.2.2.1.B. Gamma-emitting radionuclides in Mytilus edulis collected at Barsebäck in 1979. (Unit: Bq kg^{-1} fresh weight)

Part	Date	Sampling location	Depth in m	^{137}Cs	^{60}Co	^{65}Zn
Soft part	6/4	20	10	0.34	0.17 A	
Shells	"	"	"		0.54	
Soft part	9/4	49	7	0.43	0.98	0.69 A
Shells	"	"	"		4.1	

approximately valid for the Barsebäck area, these data show that the main part of the activity remains near the surface where Fucus is sampled, and only a minor fraction reaches the mussel bed at 7-10 m. This is not surprising as the radionuclides are mixed with the warm cooling water and discharged at the surface.

Table 3.2.2.2.A. Gamma-emitting radionuclides in benthic animals collected at Ringhals in 1979. (Unit: pCi kg^{-1} fresh weight)

Species	Date	Sampling location	Depth in m	^{137}Cs	^{60}Co	^{58}Co	^{65}Zn	^{110m}Ag	^{54}Mn
Mytilus edulis (soft part)	12/5	7	~ 0.3	21	172	138	470	13.6	9.8 A
Mytilus edulis (soft part)	"	8	"	24	23		52		
Mytilus edulis (soft part)	15/11	7	"	20	192	36 A	5260	19.0	
Mytilus edulis (shells)	"	"	"		159		680		31 A
Cyprina islandica (soft part)	16/11	16	25	28 B			135 A		
Cyprina islandica (shells)	"	"	"		17 B				
Modiolus modiolus (soft part)	"	14	18				430		
Modiolus modiolus (shells)	"	"	"		37				
Buccinum undatum (soft part)	"	"	"	30	16.6		280	19.9	
Buccinum undatum (shells)	"	"	"	7.7 A	50		67	4.0 A	14.2
Cancer pagurus (total)	"	"	"	44	12.4		90	12 B	
Asterias rubens	"	"	"	31	17 A		402		

Table 3.2.2.2.B. Gamma-emitting radionuclides in benthic animals collected at Ringhals in 1979. (Unit: Bq kg^{-1} fresh weight)

Species	*Date*	*Sampling location*	*Depth in m*	^{137}Cs	^{60}Co	^{58}Co	^{65}Zn	^{110m}Ag	^{54}Mn
Mytilus edulis (soft part)	12/5	7	~ 0.3	0.78	6.4	5.1	17.4	0.50	0.36
Mytilus edulis (soft part)	"	8	"	0.89	0.85		1.92		
Mytilus edulis (soft part)	15/11	7	"	0.74	7.1	1.33 A	19.5	0.70	
Mytilus edulis (shells)	"	"	"		5.9		25		1.15
Cyprina islandica (soft part)	16/11	16	25	1.04 B			5.0 A		
Cyprina islandica (shells)	"	"	"		0.63				
Modiolus modiolus (soft part)	"	14	18				15.9		
Modiolus modiolus (shells)	"	"	"		1.37				
Buccinum undatum (soft part)	"	"	"	1.11	0.61		10.4	0.74	
Buccinum undatum (shells)	"	"	"	0.28 A	1.85		2.5	0.148	0.53
Cancer pagurus (total)	"	"	"	1.63	0.46		3.3	0.44	
Asterias rubens	"	"	"	1.15	0.63		14.9		

Table 3.2.2.3. Activity ratios on fresh weight basis, Mytilus edulis soft part (from Table 3.2.2.2.A) to Brown algae (from Tables 3.2.1.2.A and 3.2.1.3.A) collected at Ringhals in 1979

Brown algae	Location	Date	^{137}Cs	^{58}Co	^{60}Co	^{54}Mn	^{65}Zn	^{110m}Ag
Fucus serratus	8	12/5			0.13		0.19	
Fucus vesiculosus	7	12/5		0.23	0.24	0.09	0.33	0.14
Fucus vesiculosus	7	15/11	0.15	0.05	0.08		0.20	0.07
Fu.ve. and Fu.se. Mean 1977-1979			0.38	0.19	0.17	0.08	0.32	0.24
S.E.			0.08	0.05	0.03	0.02	0.04	0.14
n			5	7	8	2	6	3

In Ringhals mussels were collected at the same sites as brown algae (Table 3.2.2.2), and activity ratios were calculated as previously[1)] (Table 3.2.2.3). The mean values from 1977-1979 indicate that Fucus concentrates the corrosion-products to a level approximately 5 times higher than Mytilus. Multiplying the mean activity ratios with the mean transfer factors for Fucus (Table 3.2.1.7) and normalizing to ^{60}Co gives the following relative transfer factors for Mytilus edulis:

$$^{60}Co = 1; \quad ^{58}Co = 0.6; \quad ^{54}Mn = 0.4; \quad ^{65}Zn = 7; \quad ^{110m}Ag = 3.$$

The dose commitment to a hypothetical critical individual consuming 20 kg Mytilus edulis soft parts yearly, sampled at location 7 where fishing is prohibited, would be approximately 0.8 mrem y^{-1} based on the November sample. Thus, even this extreme approach gives less than 1% of the background radiation dose.

3.2.3. γ-emitting radionuclides in fish

Corrosion product levels in fish caught near Barsebäck and Ringhals are low (Table 3.2.3.1). The dose commitment to a hypothetical critical individual consuming 100 kg fish meat yearly from the vicinity of Ringhals would be approximately 0.5 mrem y^{-1} based on results from Table 3.2.3.1. Of this dose the power plant is responsible only for 6% coming from ^{65}Zn, as the radiocesium originates from Windscale and from fallout. The ratio

$^{134}Cs/^{137}Cs$ is not different for fish caught in Denmark (Chapter 5.8). As the $^{134}Cs/^{137}Cs$ ratio in the discharge was much higher (~ 0.8), this indicates that the radiocesium contribution from Ringhals was negligible.

Table 3.2.3.1.A. Gamma-emitting radionuclides in fish collected at Barsebäck and Ringhals in 1979. (Unit: pCi kg^{-1} fresh weight)

Location		Date	Species		^{137}Cs	^{54}Mn	^{60}Co	^{134}Cs	^{65}Zn
Barsebäck	50	10/4	plaice	meat	49				
"	"	"	cod	meat	129				
"	"	"	dab	meat	54				
"	"	"	flounder	meat	81	7 A			
"	"	"	"	non-edible fraction	51	5 A	4.8		
Ringhals	14	16/11	dab	meat	100			5.7	27
"	"	"	"	bone					145 A
"	"	"	fish*	meat	96			5.5	71
"	"	"	"	bone					202

*Cod, plaice, flcunder and witch.

Table 3.2.3.1.B. Gamma-emitting radionuclides in fish collected at Barsebäck and Ringhals in 1979 (Unit: Bq kg^{-1} fresh weight)

Location		Date	Species		^{137}Cs	^{54}Mn	^{60}Co	^{134}Cs	^{65}Zn
Barsebäck	50	10/4	plaice	meat	1.81				
"	"	"	cod	meat	4.8				
"	"	"	dab	meat	2.0				
"	"	"	flounder	meat	3.0	0.26 A			
"	"	"	"	non-edible fraction	1.89	0.18 A	0.178		
Ringhals	14	16/11	dab	meat	3.7			0.21	1.00
"	"	"	"	bone					5.4 A
"	"	"	fish*	meat	3.6			0.20	2.6
"	"	"	"	bone					7.5

Cod, plaice, flounder and witch.

Table 3.2.4.1.A. Gamma-emitting radionuclides in sediment samples collected at Barsebäck in 1979

Position	Date	Depth in cm	^{137}Cs		^{60}Co		^{54}Mn	
			pCi kg^{-1}	mCi km^{-2}	pCi kg^{-1}	mCi km^{-2}	pCi kg^{-1}	mCi km^{-2}
48	7/4	0-3	438	4.6	38 A	0.40 A		
"	"	3-6	90	1.61	31 A	0.56 A		
"	"	6-9	42	0.63				
		0-9		Σ 6.8		Σ 0.96		
38 (P1)	7/5	0-2	1190	9.7	450	3.7	43	0.4
"	"	2-4	780	7.4	250	2.4	18 B	0.2 B
"	"	4-10	94	3.0			17 B	0.6 B
		0-10		Σ 20.1		Σ 6.1		Σ 1.2
38 (P2)	7/5	0-2	1190	11.9	450	4.5	31 B	0.3 B
"	"	2-4	730	8.2	139	1.5		
"	"	4-10	91	3.2				
		0-10		Σ 23.3		Σ 6.0		Σ 0.3
38 (P3)	7/5	0-2	1200	8.5	560	4.0	38 A	0.3 A
"	"	2-4	950	8.5	230	2.0	36 A	0.3 A
"	"	4-10	143	4.5				
		0-10		Σ 21.5		Σ 6.0		Σ 0.6
38 (P4)	7/5	0-2	1220	11.6	350	3.3	35 A	0.3 A
"	"	2-4	820	9.5	210	2.5	30 A	0.3 A
"	"	4-6	300	3.7	28	0.4		
		0-6		Σ 24.8		Σ 6.2		Σ 0.6
38 (P5)	7/5	0-2	1190	11.4	440	4.2	46 A	0.4 A
"	"	2-4	1080	13.0	280	3.3	46 A	0.6 A
"	"	4-10	160	5.6				
		0-10		Σ 30.0		Σ 7.5		Σ 1.0
38	8/12	0-3*	1270	16.2	264	3.4		
"	"	3-6	438	6.5	30 A	0.44 A		
"	"	6-9	100	1.63				
		0-9		Σ 24.3		Σ 3.84		

*Possibly trace of ^{125}Sb.

Table 3.2.4.i.8. Gamma-emitting radionuclides in sediment samples collected at Barsebäck in 1979.

Position	Date	Depth in cm	^{137}Cs Bq kg^{-1}	^{137}Cs Bq m^{-2}	^{60}Co Bq kg^{-1}	^{60}Co Bq m^{-2}	^{54}Mn Bq kg^{-1}	^{54}Mn Bq m^{-2}
48	7/4	0-3	16.2	170	1.4 A	14.8 A		
"	"	3-6	3.3	60	1.1 A	20.7 A		
"	"	6-9	1.6	23				
		0-9		Σ 253		Σ 35.5		
38 (P1)	7/5	0-2	44	359	16.6	137	1.59	14.8
"	"	2-4	29	274	9.2	89	0.67 B	7.4 B
"	"	4-10	3.5	111			0.63 B	22.2 B
		0-10		Σ 744		Σ 226		Σ 44.4
38 (P2)	7/5	0-2	44	440	16.6	166	1.15 B	11.1 B
"	"	2-4	27	303	5.1	56		
"	"	4-10	3.4	118				
		0-10		Σ 861		Σ 222		Σ 11.1
38 (P3)	7/5	0-2	44	314	21	148	1.4 A	11.1 A
"	"	2-4	35	314	8.5	74	1.3 A	11.1 A
"	"	4-10	5.3	166				
		0-10		Σ 794		Σ 222		Σ 22.2
38 (P4)	7/5	0-2	45	429	12.9	122	1.30 A	11.1 A
"	"	2-4	30	352	7.8	92	1.11 A	11.1 A
"	"	4-6	11.1	137	1.04	15		
		0-6		Σ 918		Σ 229		Σ 22.2
38 (P5)	7/5	0-2	44	422	16.3	155	1.70 A	14.8 A
"	"	2-4	40	481	10.4	122	1.70 A	22.2 A
"	"	4-10	5.9	207				
		0-10		Σ 1110		Σ 277		Σ 37.0
38	8/12	0-3*	47	599	9.8	126		
"	"	3-6	16.2	240	1.1 A	16 A		
"	"	6-9	3.7	60				
		0-9		Σ 899		Σ 142		

*Possibly trace of ^{125}Sb.

3.2.4. γ-emitting radionuclides in sea sediments

As previously sediments sampled by the HAPS bottom corer[18] were sliced in 3-cm thick sections and analysed (Tables 3.2.4.1 and 3.2.4.2), and in addition our γ-spectrometric data from a Nordic intercalibration held at Barsebäck May 1979 (P 1 to P 5 in Table 3.2.4.1) are reported. The results from the intercalibration of 5 bottom corers and several Nordic laboratories performing α- and γ-spectrometric analyses on sediments will be reported elsewhere.

Table 3.2.4.2.A. Gamma-emitting radionuclides in sediment samples collected at Ringhals in 1979

Position	Date	Depth in cm	^{137}Cs		^{60}Co	
			pCi kg^{-1}	mCi km^{-2}	pCi kg^{-1}	mCi km^{-2}
1	11/5	0-3	435	10.4	445	10.6
"	"	3-6	211	7.6		
		0-6		Σ 18.0		Σ 10.6
2	11/5	0-3	578	11.4	207	4.1
"	"	3-6	339	10.2	58	1.8
"	"	6-9	145	5.7		
		0-9		Σ 27.3		Σ 5.9
3	11/5	0-3	236	8.0	247	8.3
"	"	3-6	163	5.8		
		0-6		Σ 13.8		Σ 8.3
4	11/5	0-3	168	6.1	149	5.4
"	"	3-6	138	4.7	123	4.2
"	"	6-9	85	2.7	43	1.4
"	"	9-10	125	1.0	120	1.0
		0-10		Σ 14.5		Σ 12.0
2	9/11	0-3	561	10.8	153	2.9
"	"	3-6	286	8.8	75	2.3
"	"	6-9	126	4.8		
		0-9		Σ 24.4		Σ 5.2

Table 3.2.4.2.2. Gamma-emitting radionuclides in sediment samples collected at Ringhals in 1979

Position	Date	Depth in cm	^{137}Cs		^{60}Co	
			Bq kg^{-1}	Bq m^{-2}	Bq kg^{-1}	Bq m^{-2}
1	11/5	0-3	16.1	385	16.5	392
"	"	3-6	7.8	281		
		0-6		Σ 666		Σ 392
2	11/5	0-3	21.4	422	7.7	152
"	"	3-6	12.5	377	2.7	67
"	"	6-9	5.4	211		
		0-9		Σ1010		Σ 219
3	11/5	0-3	8.1	296	9.1	307
"	"	3-6	6.0	215		
		0-6		Σ 511		Σ 307
4	11/5	0-3	6.2	226	5.5	200
"	"	3-6	5.1	174	4.6	155
"	"	6-9	3.1	100	1.6	52
"	"	9-10	4.6	37	4.4	37
		0-10		Σ 537		Σ 444
2	9/11	0-3	20.8	400	5.7	107
"	"	3-6	10.6	326	2.8	85
"	"	6-9	4.7	178		
		0-9		Σ 904		Σ 192

4. FALLOUT NUCLIDES IN THE ABIOTIC ENVIRONMENT

by A. Aarkrog and J. Lippert

4.1. Air

4.1.1. Strontium-90

The mean air activity level for 1979: 0.39 fCi ^{90}Sr m^{-3}, i.e. 0.3 times the 1978 level. The maximum activity in 1979 was measured in June at 0.69 fCi ^{90}Sr m^{-3}.

Table 4.1.1.A. Strontium-90 in air collected at Risø in 1979

Month	fCi ^{90}Sr m^{-3}
Jan	0.32
Feb	0.36
March	0.44
April	0.61
May	0.66
June	0.69
July	0.39
Aug	0.41
Sept	0.26
Oct	0.21
Nov	0.157
Dec	0.171
1979	0.39

Table 4.1.1.B. Strontium-90 in air collected at Risø in 1979

Month	*Bq m^{-3}*
Jan	11.8×10^{-6}
Feb	13.3×10^{-6}
March	16.3×10^{-6}
April	22.6×10^{-6}
May	24.4×10^{-6}
June	25.5×10^{-6}
July	14.4×10^{-6}
Aug	15.2×10^{-6}
Sept	9.6×10^{-6}
Oct	7.8×10^{-6}
Nov	5.8×10^{-6}
Dec	6.3×10^{-6}
1979	14.4×10^{-6}

Figure 4.1.1 shows the quarterly levels of ^{90}Sr in air since 1957.

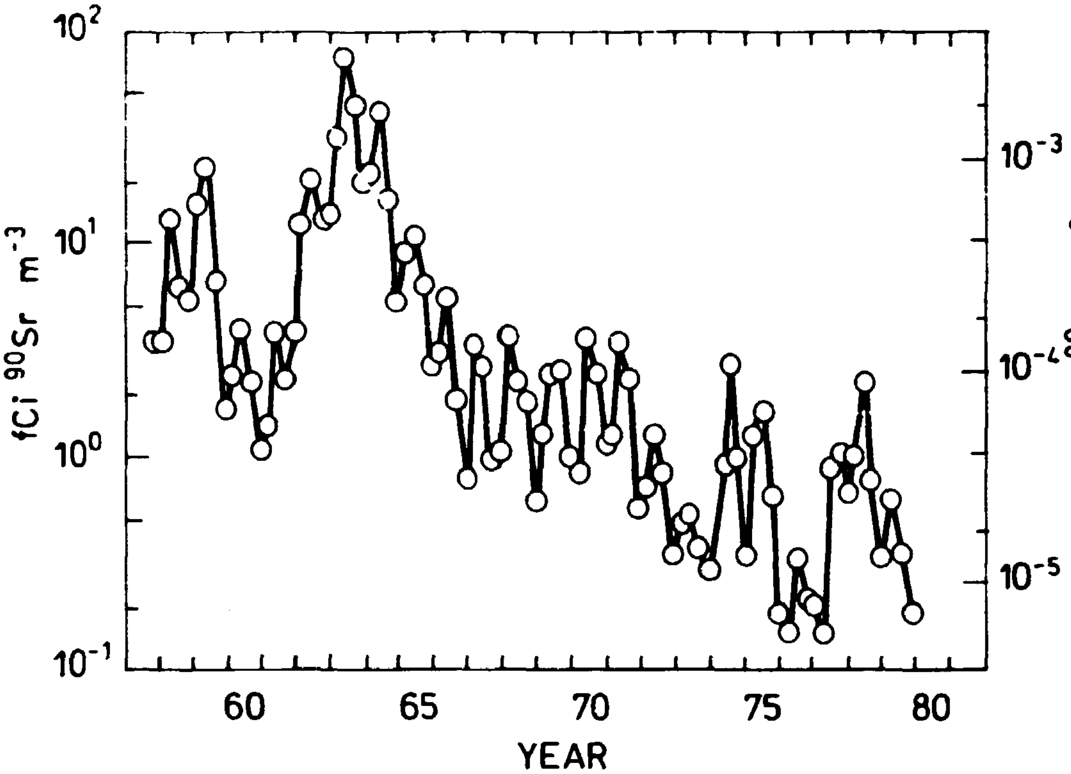


Fig. 4.1.1. Quarterly ^{90}Sr levels in air, 1957-1979.

4.1.2. Cesium-137

As in 1962-1978, samples of air were collected twice a week by means of the air sampler described in Risø Report No. 23[1]. The filters were measured on a 100 cm^3 Ge(Li) detector[8]. Table 4.1.2 shows the monthly means of the ^{137}Cs determinations (cf. also fig. 4.1.2). The peak value was observed in June. The mean level in 1979 was 0.27 times the 1978 mean. The ^{137}Cs/^{90}Sr mean ratio in the air filter was 2.2 in 1979.

Since September a new air sampler was installed at Risø (cf. fig. 3.1.2.1 and fig. 4.1.3). This sampler collects the air dust on 6 glass fibre filters each 56 × 48 cm^2. The filters are changed every week and collects approximately 275,000 m^3 in a week. The ^{137}Cs concentrations determined by the new sampler were approximately 70% of that from the old, the difference is probably due to calibration difficulties.

Table 4.1.2.A. Cesium-137 in glass-fibre air filtres collected twice a week at Risø in 1979 (Unit: fCi m^{-3})

Month	Old sampler	New sampler**
Jan	0.75±0.11	
Feb	0.89±0.07	
March	1.05±0.07	
April	1.60±0.29	
May	1.81±0.27	
June	1.92±0.39	
July	0.56±0.06	
Aug	0.61±0.05	
Sept	0.41±0.06	0.31±0.05*
Oct	0.30±0.03	0.20±0.02
Nov	0.18±0.03$^{\Delta}$	0.14±0.03
Dec	0.17±0.01$^{\Delta}$	0.11±0.01
1979	0.85	

The error term is the S.E. of the mean of the activity found in 8 or 9 filtres collected during a month, except for the new one, which was 4 filtres a month.

*Only 3 weeks.

$^{\Delta}$Collected once a week.

**Cf. text.

Table 4.1.2.B. Cesium-137 in glass-fibre air filters collected twice a week at Risø in 1979 (Unit: Bq m^{-3})

Month	Old sampler	New sampler
Jan	$(28 \pm 4) \times 10^{-6}$	
Feb	$(33 \pm 3) \times 10^{-6}$	
March	$(39 \pm 3) \times 10^{-6}$	
April	$(59 \pm 11) \times 10^{-6}$	
May	$(67 \pm 10) \times 10^{-6}$	
June	$(71 \pm 14) \times 10^{-6}$	
July	$(21 \pm 2) \times 10^{-6}$	
Aug	$(23 \pm 2) \times 10^{-6}$	
Sept	$(15.2 \pm 2.2) \times 10^{-6}$	$(11.5 \pm 1.8) \times 10^{-6*}$
Oct	$(11.1 \pm 1.1) \times 10^{-6}$	$(7.4 \pm 0.7) \times 10^{-6}$
Nov	$(6.7 \pm 1.1) \times 10^{-6\Delta}$	$(5.2 \pm 1.1) \times 10^{-6}$
Dec	$(6.3 \pm 0.4) \times 10^{-6\Delta}$	$(4.1 \pm 0.4) \times 10^{-6}$
1979	32×10^{-6}	

The error term is the S.E. of the mean of the activity found in 8 or 9 filtres collected during a month, except for the new one, which was 4 filtres a month.

**Only 3 weeks.*

$^{\Delta}$Collected once a week.

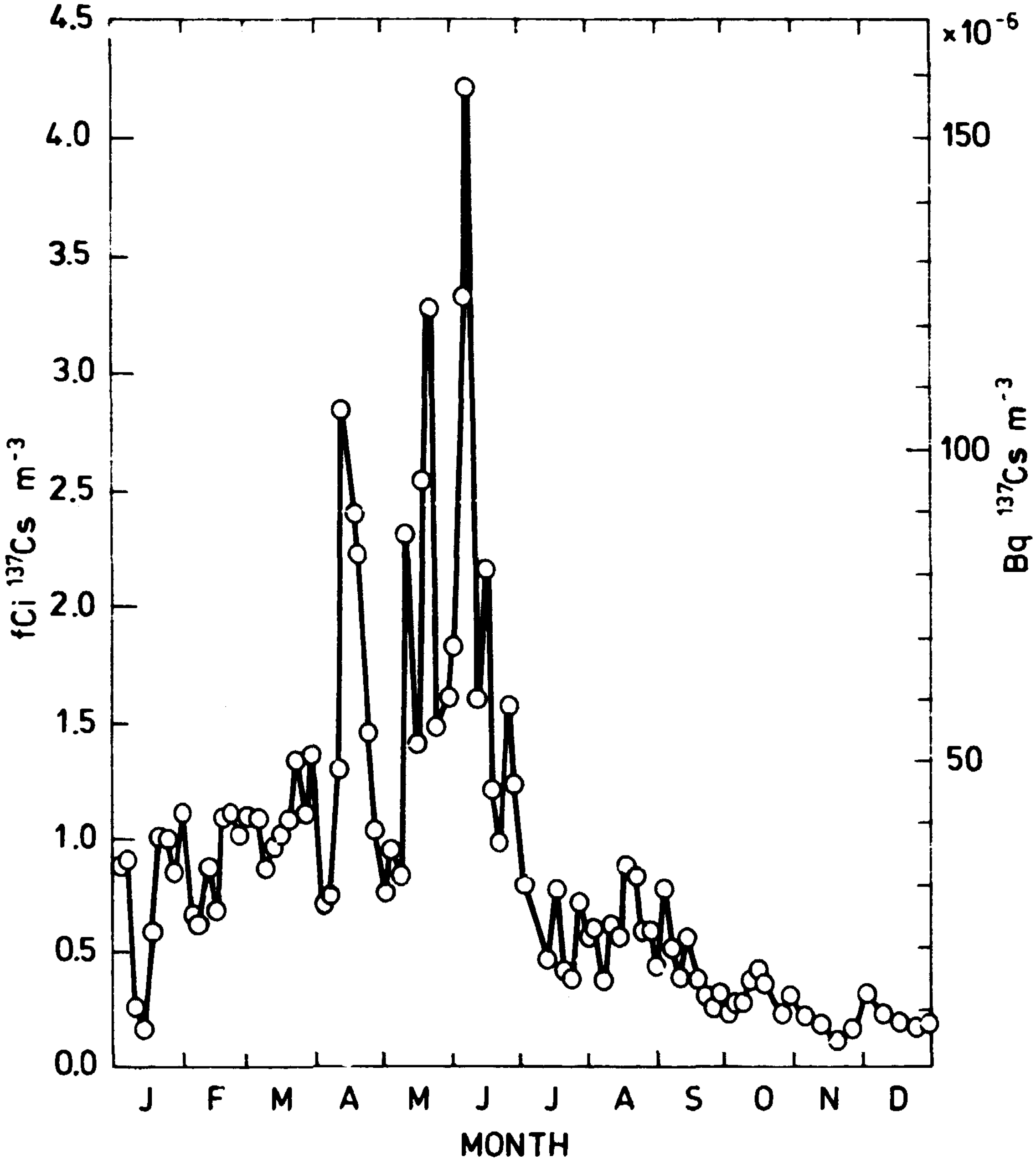


Fig. 4.1.2. Cesium-137 in ground level air at Risø in 1979.

4.1.3. Short-lived γ-emitting nuclides in air and precipitation

On December 14, 1978, China tested a nuclear weapon in the kilotons range in the atmosphere. Fresh fallout (^{141}Ce, ^{103}Ru) was detectable in ground-level air during the first half of January.

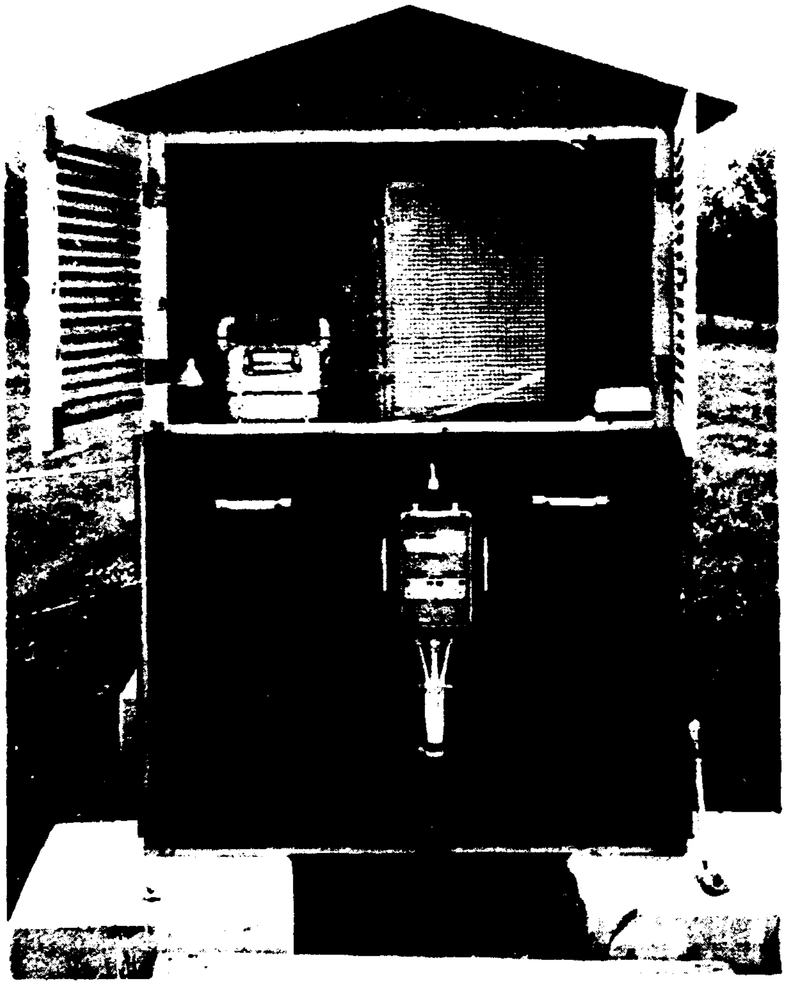


Fig. 4.1.3. The "New Air Sampler". Two of the six filters are visible. Total filterarea 1.6 m^2. Capacity: ~ 0.3 m^3 s^{-1} per m^2 filter.

4.2. Strontium-90 in precipitation

Samples of rain water were collected in 1979 from the State experimental farms (cf. fig. 4.2) in accordance with the principles laid down in Risø Report No. 63, p. 51[1].

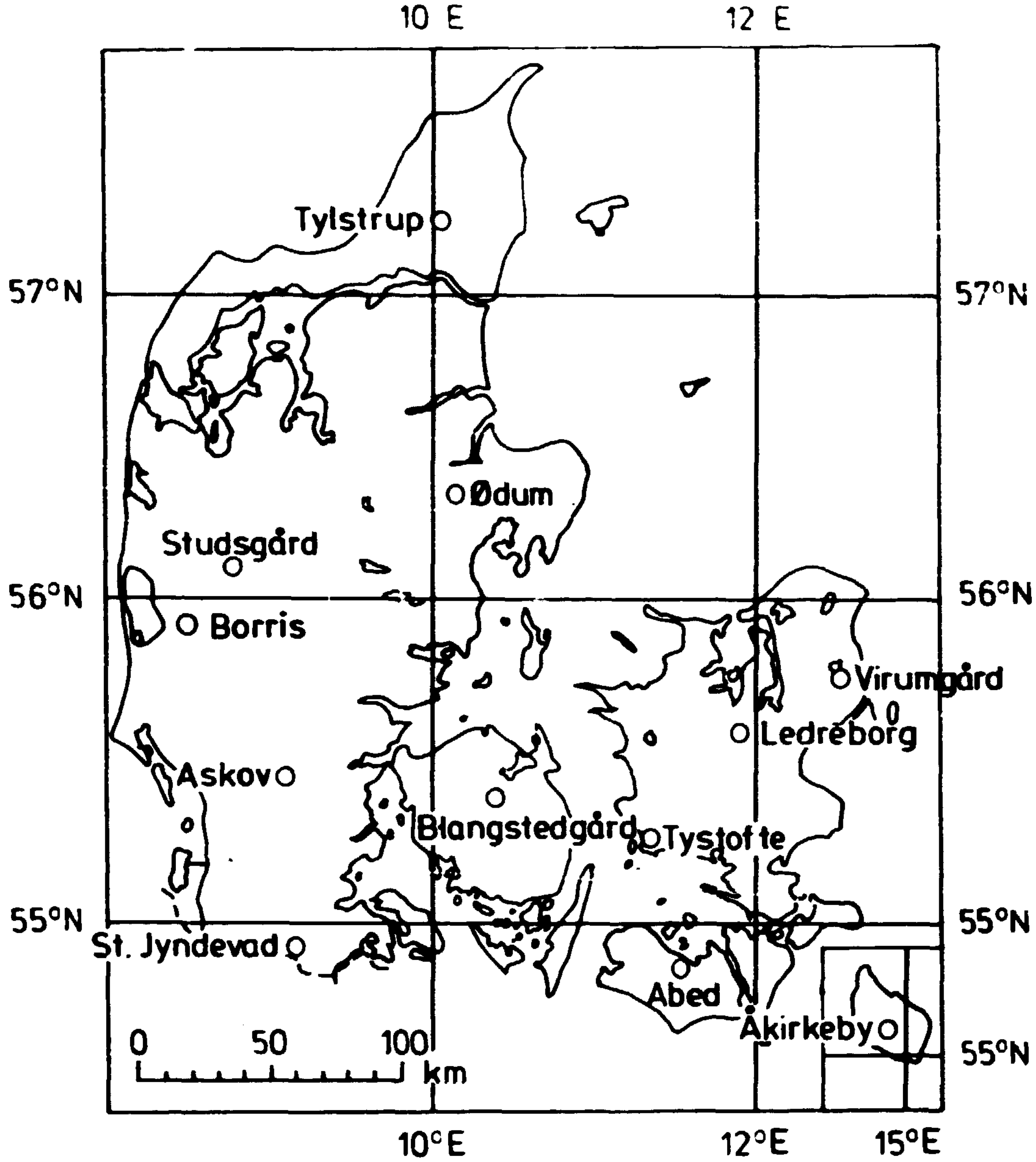


Fig. 4.2. State experimental farms in Denmark.

Table 4.2.1 shows the results of the ^{90}Sr determinations and Tables 4.2.2 and 4.2.3 the analysis of variance of the results.

The maximum concentration in precipitation occurred in May-June when the mean content in precipitation was 0.52 pCi $^{90}Sr\ l^{-1}$ (cf. also the air measurements in 4.1.1), and the maximum fall-out rate also occurred in May-June, 0.056 mCi $^{90}Sr\ km^{-2}$. The mean levels for ten State experimental farms were 0.166 mCi

Table 4.2.1.A. Strontium-90 fall-out in Denmark in 1979

Period	Unit		Tylstrup	Studs-gård*	Ødum	Askov	St. Jyndevad	Blangstedgård	Tystofte	Abed	Åkirkeby	Ledreborg	Mean
Jan-Feb	pCi l^{-1}		0.52	0.26	0.56 A	0.34	0.31	0.42	1.30	0.47 A	0.62	0.70 A	0.44
	mCi km^{-2}		0.0135	0.0085	0.0061A	0.0140	0.0110	0.0120	0.0089	0.0064A	0.0107	0.0051A	0.0096
March-April	pCi l^{-1}		0.34	0.67	0.42	0.28	0.44	0.53	0.65	0.48	0.46	0.45	0.46
	mCi km^{-2}		0.030	0.056	0.037	0.032	0.049	0.044	0.030	0.034	0.029	0.025	0.037
May-June	pCi l^{-1}		0.32	0.42	0.44	0.50	0.63	0.36	0.62	0.61	0.82	0.97	0.52
	mCi km^{-2}		0.048	0.050	0.049	0.054	0.082	0.056	0.060	0.045	0.050	0.062	0.056
July-Aug	pCi l^{-1}		0.23	0.26	0.166	0.30	0.32	0.26	0.29	0.24	0.130 B	0.150	0.23
	mCi km^{-2}		0.030	0.0119	0.028	0.045	0.039	0.025	0.045	0.037	0.0168B	0.022	0.030
Sept-Oct	pCi l^{-1}		0.126	0.183	0.142	0.127	0.142	0.25	0.28	0.194	0.51	0.60	0.188
	mCi km^{-2}		0.0164	0.036	0.0107	0.020	0.0160	0.0128	0.0143	0.0132	0.0131	0.0150	0.0168
Nov-Dec	pCi l^{-1}		0.093	0.077	0.075	0.135	0.057	0.065	0.092	0.072	0.096	0.140	0.086
	mCi km^{-2}		0.0128	0.021	0.0124	0.0159	0.0156	0.0129	0.0162	0.0139	0.0161	0.026	0.0163
1979	pCi l^{-1}	$\bar{x}$	0.23	0.24	0.23	0.26	0.27	0.27	0.33	0.26	0.29	0.32	0.27
	mCi km^{-2}	Σ	0.151	0.183	0.143	0.181	0.213	0.163	0.174	0.150	0.136	0.155	0.166
mm precipitation Σ			662	751	619	688	785	613	532	574	464	485	617

*From Nov-Dec Studsgård has been replaced by Borris (cf. Fig. 4.2).

Table 4.2.1.B. Strontium-90 fall-out in Denmark in 1979

Period	Unit		Tylstrup	Studs-gård*	Ødum	Askov	St. Jyndevad	Blangstedgård	Tystofte	Abed	Åkirkeby	Ledreborg	Mean
Jan-Feb	Bq m^{-3}		19.2	9.6	21 A	12.6	11.5	15.5	48	17.4 A	23	26 A	16.3
	Bq m^{-2}		0.50	0.31	0.23A	0.52	0.41	0.44	0.33	0.24A	0.40	0.189A	0.36
March-April	Bq m^{-3}		12.6	25	15.5	10.4	16.3	19.6	24	17.8	17.0	16.6	17.0
	Bq m^{-2}		1.11	2.1	1.37	1.18	1.8	1.63	1.11	1.26	1.07	0.92	1.37
May-June	Bq m^{-3}		11.8	15.5	16.3	18.5	23	13.3	23	23	30	36	19.2
	Bq m^{-2}		1.78	1.85	1.81	2.0	3.0	2.1	2.2	1.66	1.85	2.3	2.1
July-Aug	Bq m^{-3}		8.5	9.6	6.1	11.1	11.8	9.6	10.7	8.9	4.8 B	5.6	8.5
	Bq m^{-2}		1.11	0.44	1.04	1.66	1.44	0.92	1.66	1.37	0.62B	0.81	1.11
Sept-Oct	Bq m^{-3}		4.7	6.8	5.3	4.7	5.3	9.2	10.4	7.2	18.9	22	7.0
	Bq m^{-2}		0.61	1.33	0.40	0.74	0.59	0.47	0.53	0.49	0.48	0.56	0.62
Nov-Dec	Bq m^{-3}		3.4	2.8	2.8	5.0	2.1	2.4	3.4	2.7	3.6	5.2	3.2
	Bq m^{-2}		0.47	0.78	0.46	0.59	0.58	0.48	0.60	0.51	0.60	0.96	0.60
1979	Bq m^{-3}	$\bar{x}$	8.5	8.9	8.5	9.6	10.0	10.0	12.2	9.6	10.7	11.8	10.0
	Bq m^{-2}	Σ	5.6	6.8	5.3	6.7	7.9	6.0	6.4	5.6	5.0	5.7	6.1
m precipitation Σ			0.662	0.751	0.619	0.688	0.785	0.613	0.532	0.574	0.464	0.485	0.617

*From Nov-Dec Studsgård has been replaced by Borris (cf. Fig. 4.2).

Table 4.[illegible]. Analysis of variance of ln pCi ^{90}Sr l^{-1} precipitation in 1979 (from Table 4.2.1.A)

Variation	SSD	f	s^2	v^2	P
Between months	25.191	5	5.038	38.057	> 99.95%
Between locations	2.256	9	0.251	1.894	-
Remainder	5.957	45	0.132	15.127	

Table 4.2.3. Analysis of variance of ln pCi ^{90}Sr km^{-2} precipitation in 1979 (from Table 4.2.1.A)

Variation	SSD	f	s^2	v^2	P
Between months	21.159	5	4.232	44.050	> 99.95%
Between locations	0.979	9	0.109	1.132	-
Remainder	4.323	45	0.096	0.259	

^{90}Sr km^{-2} and 0.27 pCi ^{90}Sr l^{-1}. The fallout rate in 1979 was 0.36 times that observed in 1978. The ^{90}Sr deposition in 1979 was 1.1 times higher in Jutland than in the Islands. The ANOVA showed no significant local variation in 1979.

A comparison between the yearly amounts of precipitation found in the rain gauges used by the Danish Meteorological Institute[9)] and the amounts collected in our rain bottles at the same ten locations in 1979 showed a mean ratio of 1.21±0.16 (1 SD) between the two sampling systems.

Table 4.2.5 shows the ^{137}Cs levels in rain water collected at a new 10 m^2 rain collector. The ^{137}Cs concentrations in the rain were as in 1978 lower than expected from the ^{90}Sr precipitation levels (4.2.1) and from the ^{137}Cs/^{90}Sr air ratio (4.1.2). The effluent from the ion exchange column contains ^{137}Cs and from 1980 the amount of resin in the column has been increased in order to improve the efficiency of the column.

Table 4.2.5.A. Cesium-137 in rain water collected in a big ion-exchange column collector at Risø in 1979 (sampling area 10 m^2)

Period	mm	pCi ^{137}Cs l^{-1}	mCi ^{137}Cs km^{-2}
12/4-30/4	14.6	0.63	0.0092
May	45.5	0.99	0.045
June	22.5	0.48	0.0108
July	24.0	0.32	0.0077
August	86.0	0.124	0.0107
September	27.5	0.194	0.0053
October	29.0	0.140	0.0041
November	54.0	0.111	0.0060
December	77.0	0.106	0.0082
1979	Σ 380	0.28	Σ 0.107

Table 4.2.5.B. Cesium-137 in rain water collected in a big ion-exchange column collector at Risø in 1979 (sampling area 10 m^2)

Period	m	Bq m^{-3}	Bq m^{-2}
12/4-30/4	0.015	23	0.34
May	0.046	37	1.66
June	0.023	17.8	0.40
July	0.024	11.8	0.28
August	0.086	4.6	0.40
September	0.028	7.2	0.196
October	0.029	5.2	0.152
November	0.054	4.1	0.22
December	0.077	3.9	0.30
1979	Σ 0.38	10.4	Σ 3.9

4.3. Fresh water

4.3.1. Strontium-90 in ground water

As in previous years[1], ground water was collected in March from the nine locations selected by the Geological Survey of

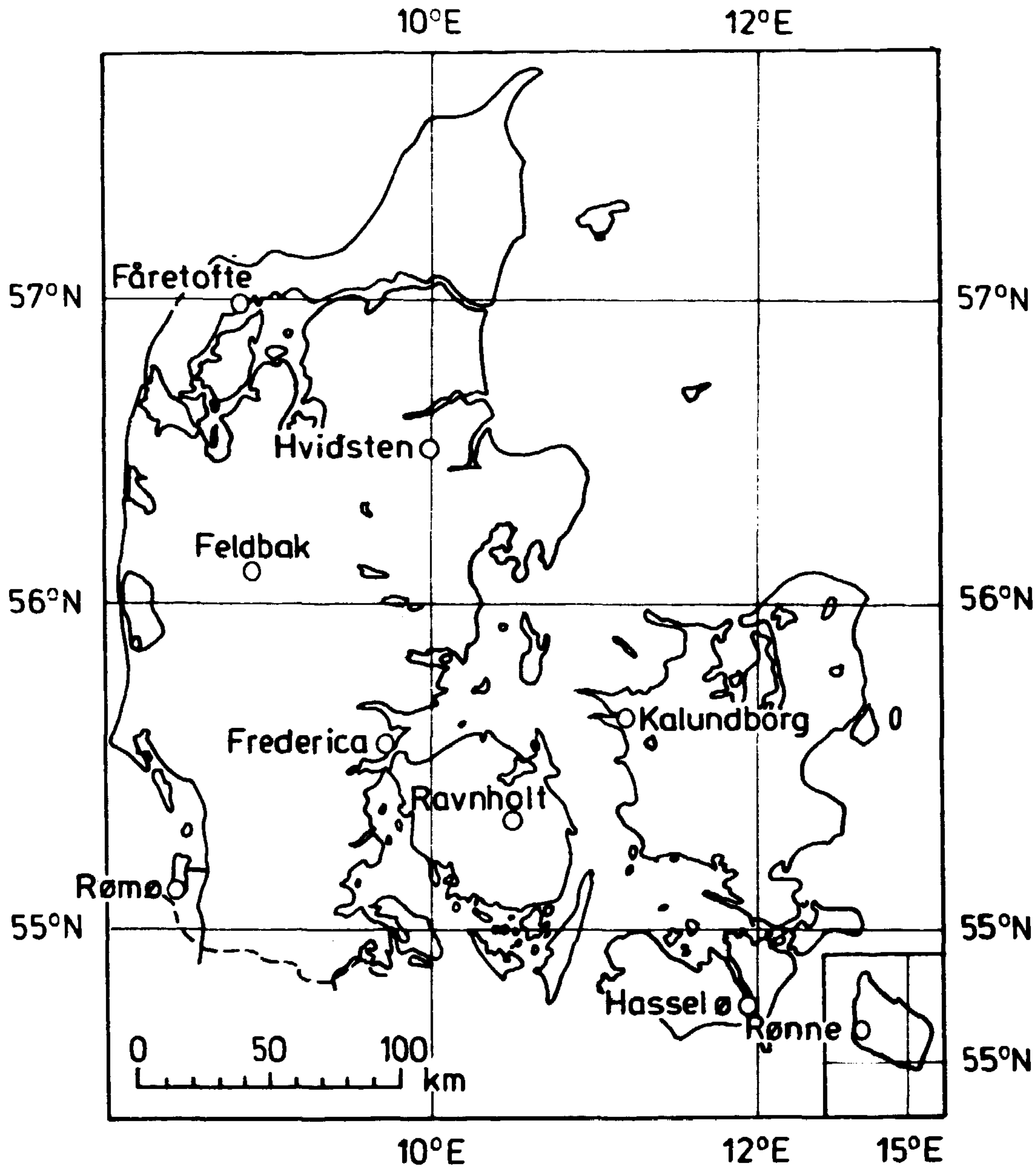


Fig. 4.3.1.1. Ground water sampling locations in Denmark.

Denmark. Figure 4.3.1.1 shows the sample locations and table 4.3.1 the results of the ^{90}Sr analyses.

The median level of ^{90}Sr in 1979 was compatible with the values found since 1967 (cf. fig. 4.3.1.2).

As appears from fig. 4.3.1.3, the ^{90}Sr levels in ground water from Feldbak have been around 1.5-2 pCi l^{-1} in later years.

^{137}Cs was not measurable in 45 l samples of Feldbak water from 1977, 1978, 1979 and 1980; the levels must have been less than 0.2 pCi ^{137}Cs l^{-1}.

Table 4.3.1.A. Strontium-90 in ground water collected in March 1979

Location	fCi ^{90}Sr l^{-1}	g Ca l^{-1}
Hvidsten	0.6	0.077
Feldbak	1880	0.030
Rømø	4.8	0.040
Rønne new	1.5 A	0.010
Rønne old	17	0.042
Hasselø	4.7 B	0.143
Fåretofte	2.0	0.122
Kalundborg	37	0.036
Ravnholt	5.9 A	0.135
Fredericia	19	0.088
Geometric mean	5.2*	0.072**
Median	5.4	0.060

A sample of ground water from Maglekilde in Roskilde contained 24 fCi ^{90}Sr l^{-1} and 0.0876 g Ca l^{-1}.

* Feldbak was not included in the geometric mean.

** Arithmetic mean.

Table 4.3.1.B. Strontium-90 in ground water collected in March 1979

Location	*Bq m^{-3}*	*kg Ca m^{-3}*
Hvidsten	*0.02*	*0.077*
Feldbak	*70*	*0.030*
Rømø	*0.18*	*0.040*
Rønne new	*0.056 A*	*0.010*
Rønne old	*0.62*	*0.042*
Hasselø	*0.17 B*	*0.143*
Fåretofte	*0.07*	*0.122*
Kalundborg	*1.38*	*0.036*
Ravnholt	*0.22 A*	*0.135*
Fredericia	*0.70*	*0.088*
Geometric mean	*0.19**	*0.072***
Median	*0.20*	*0.06*

A sample of ground water from Maglekilde in Roskilde contained 0.89 Bq m^{-3} and 0.0876 kg Ca m^{-3}.

** and ** cf. notes to Table A.*

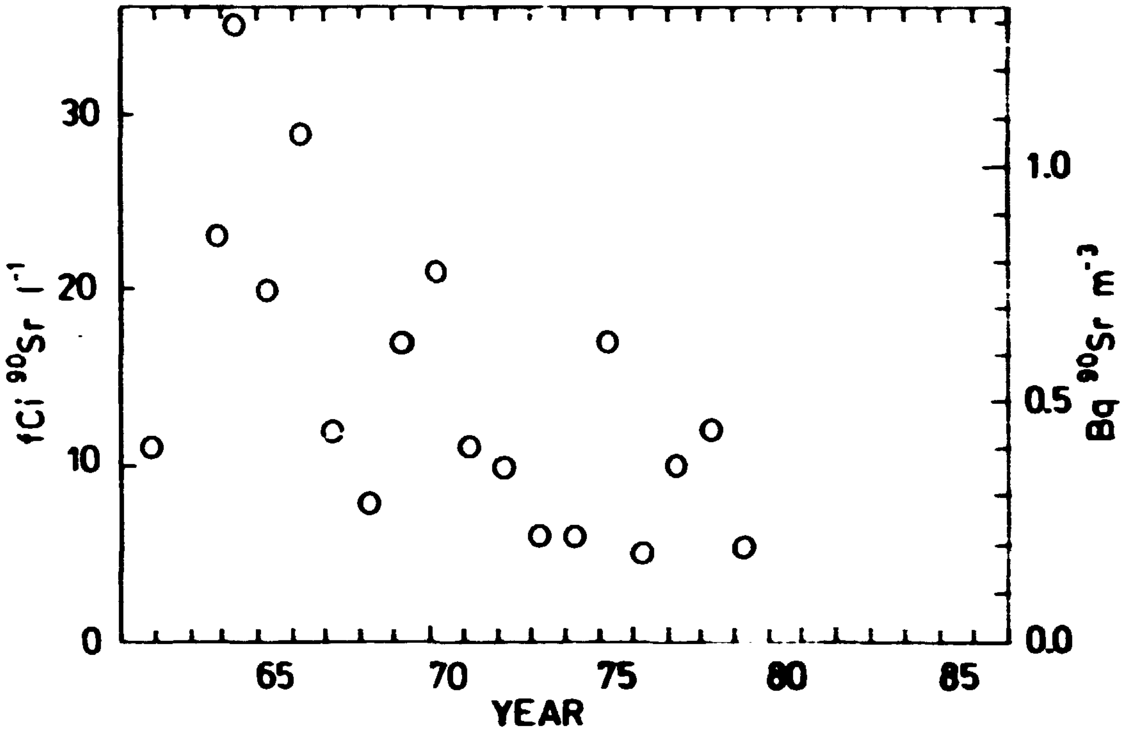


Fig. 4.3.1.2. Median ^{90}Sr levels in Danish ground water, 1961-1979.

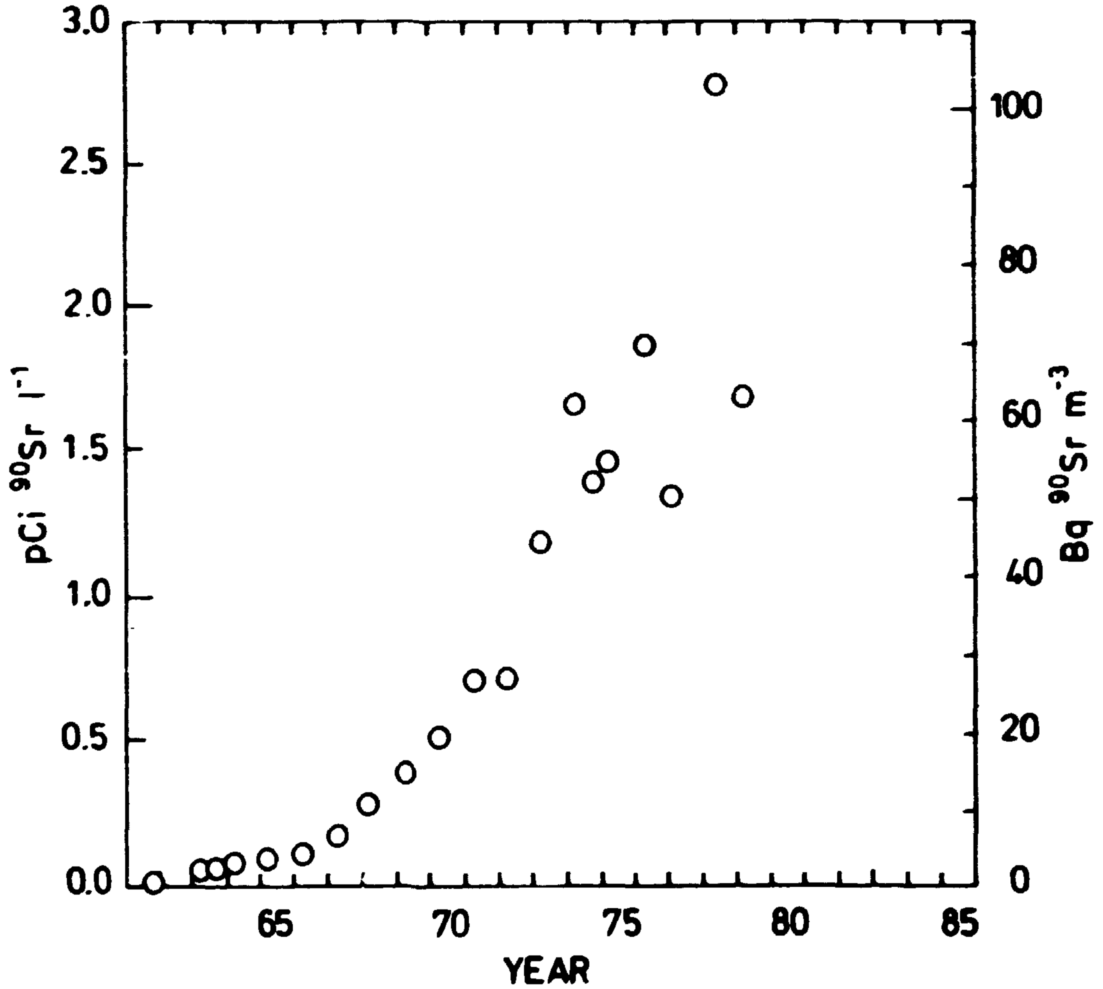


Fig. 4.3.1.3. Strontium-90 in ground water at Feldbak 1961-1979.

4.3.2. Strontium-90 in fresh water from Danish streams and lakes

In February 1979 we collected fresh water from Danish lakes and streams from the locations shown in fig. 4.3.2.1. The results are shown in Table 4.3.2 and fig. 4.3.2.2 shows the ^{90}Sr concentrations since 1971.

The levels in streams have been nearly constant during the seventies and so have the concentrations in lakes except in 1977. The various locations have throughout the period shown the same pattern. Ribe å shows approximately 4 times lower ^{90}Sr concentrations than Læså and Flyndersø is approximately 8

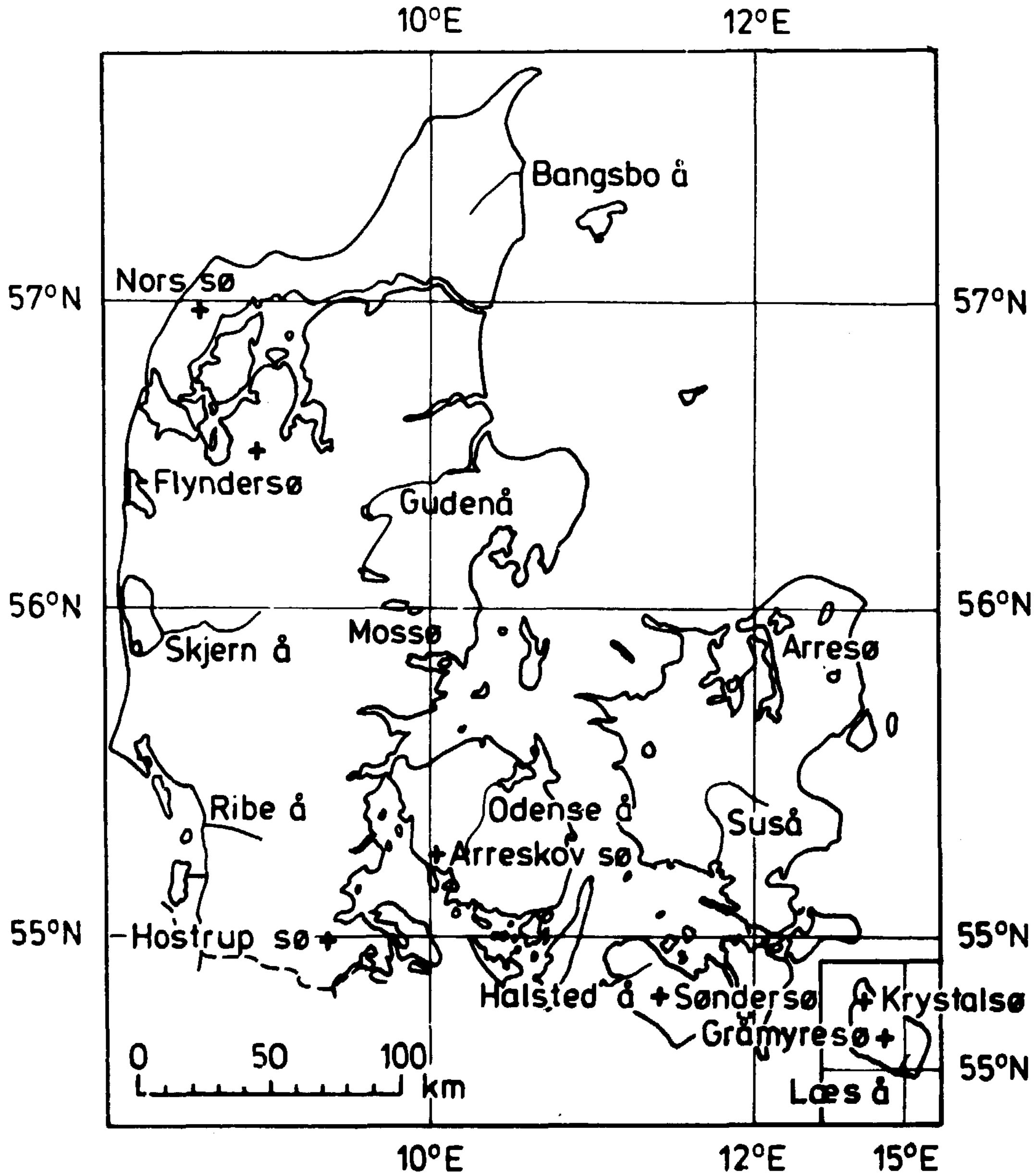


Fig. 4.3.2.1. Sample locations for fresh water from Danish streams and lakes.

Table 4.3.2.A. Strontium-90 in Danish streams and lakes in February 1979

Zone			Streams		Lakes		
			pCi ^{90}Sr l^{-1}	g Ca l^{-1}		pCi ^{90}Sr l^{-1}	g Ca l^{-1}
I:	North Jutland	Bangsbo å	0.40	0.045	Norssø	1.98	0.044
II:	East Jutland	Guden å	0.180	0.055	Mossø	0.35	0.060
III:	West Jutland	Skjern å	0.23	0.030	Flyndersø	0.25	0.044
IV:	South Jutland	Ribe å	0.134	0.069	Hostrup sø	2.79	0.039
V:	Funen	Odense å	0.31	0.116	Arreskov sø	1.17	0.121
VI:	Zealand	Suså	0.32	0.115	Arresø	0.89	0.079
VII:	Lolland-Falster	Halsted å	0.46	0.211	Søndersø	1.57	0.111
VIII:	Bornholm*	Læså	0.57	0.068	Almindingen sø	0.88	0.032
Mean			0.33	0.089		1.24	0.066
±1 S.E.			0.05	0.021		0.30	0.012

*Collected in June.

Table 4.3.2.B. Strontium-90 in Danish streams and lakes in February 1979

Zone			Streams		Lakes		
			Bq m^{-3}	kg Ca m^{-3}		Bq m^{-3}	kg Ca m^{-3}
I:	North Jutland	Bangsbo å	14.8	0.045	Norssø	73	0.044
II:	East Jutland	Guden å	6.7	0.055	Mossø	13.0	0.060
III:	West Jutland	Skjern å	8.5	0.030	Flyndersø	9.2	0.044
IV:	South Jutland	Ribe å	5.0	0.069	Hostrup sø	103	0.039
V:	Funen	Odense å	11.5	0.116	Arreskov sø	43	0.121
VI:	Zealand	Suså	11.8	0.115	Arresø	33	0.079
VII:	Lolland-Falster	Halsted å	17.0	0.211	Søndersø	58	0.111
VIII:	Bornholm*	Læså	21.1	0.068	Almindingen sø	33	0.032
Mean			12.1	0.089		46	0.066

*Collected in June

times lower than Norssø. The constancy of the ^{90}Sr levels in streams and lakes suggests that these concentrations depend primarily upon the accumulated ^{90}Sr in the soil rather than upon the ^{90}Sr concentrations in precipitation.

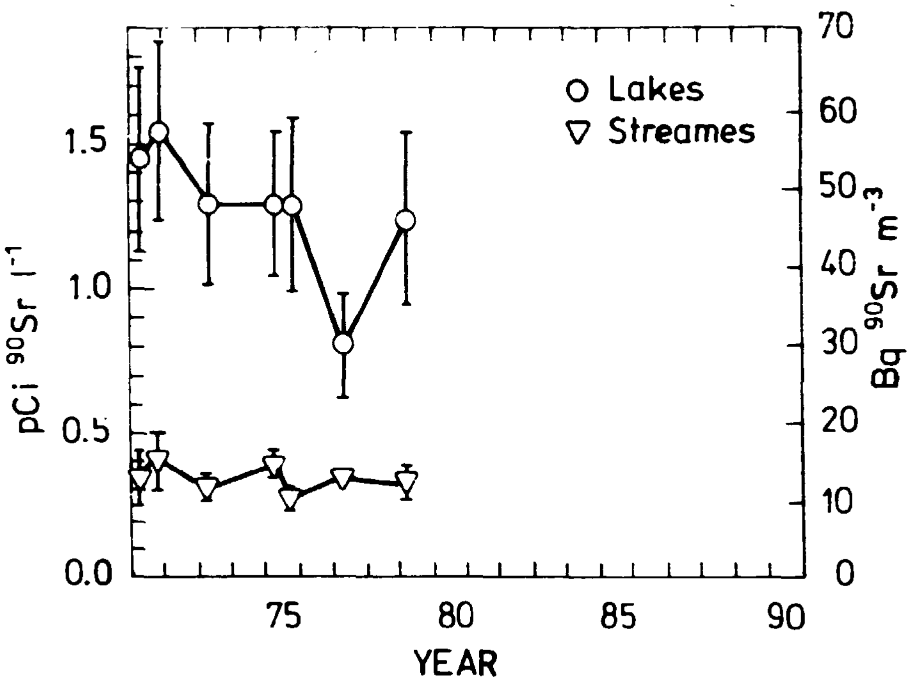


Fig. 4.3.2.2. Strontium-90 concentrations (± 1 SE) in 8 Danish streams and 8 Danish lakes collected every second year since 1971.

4.3.3. Strontium-90 in Danish drinking water

Drinking water was collected from the eight zones in the years 1965-1973[1]. Since then no samples have been collected. In April 1979 the sampling was taken up again. The water was collected in six towns in each zone and in Copenhagen. The sampling represented the drinking water of 50% of the Danish population. The results of the ^{90}Sr determinations are shown in Table 4.3.3. Compared with the previous measurements, there is no significant change in the Danish drinking water ^{90}Sr concentrations. The median level is on the order of 10 fCi ^{90}Sr l^{-1}, i.e. similar to that observed in Danish ground water. We have thus found no indications of high ^{90}Sr concentrations similar to the water from Feldbak (cf. Table 4.3.1), and the contribution of surface water to the Danish drinking water does not enhance the drinking water ^{90}Sr levels to concentrations similar to those found in Danish streams and lakes (cf. Table 4.3.2).

Table 4.3.3.A. Strontium-90 in Danish drinking water in April 1979

Zone		fCi ^{90}Sr l^{-1}	g Ca l^{-1}
I:	North Jutland	24.6	0.065
II:	East Jutland	10.3	0.064
III:	West Jutland	12.3	0.0034
IV:	South Jutland	2.1 B	0.084
V:	Funen	2.6 A	0.107
VI:	Zealand	66.8	0.102
VII:	Lolland-Falster	0.7 B	0.104
VIII:	Bornholm*	49.5	0.077
Mean		21	0.076
Copenhagen*		18.9	0.088
Population-weighted mean		22.5	0.075
Median		11.3	0.080

*Collected in June.

Table 4.3.3.B. Strontium-90 in Danish drinking water in April 1979

Zone		Bq m^{-3}	kg Ca m^{-3}
I:	North Jutland	0.91	0.065
II.	East Jutland	0.38	0.064
III:	West Jutland	0.46	0.0034
IV:	South Jutland	0.078	0.084
V:	Funen	0.096	0.107
VI:	Zealand	2.5	0.102
VII:	Lolland-Falster	0.024	0.104
VIII:	Bornholm*	1.83	0.077
Mean		0.78	0.076
Copenhagen*		0.70	0.088
Population-weighted mean		0.83	0.075
Median		0.42	0.080

*Collected in June

4.4. Strontium-90, Cesium-137 and Cesium-134 in sea water in 1979

As in previous years, sea water samples were collected by M/S Fyrholm in the summer from inner Danish waters. The winter sampling was made partly by car from land in November 1979-January 1980, due to bad weather conditions (cf. Table 4.4.1 and figs. 4.4.1 and 4.4.2). Furthermore, sea water samples were collected at Barsebäck in the Sound (Table 4.4.2), and at Ringhals in the Kattegat (Table 4.4.3). Samples from the North Sea were obtained from the State ship "Martin Knudsen", "Nordjylland" and "Nordsøen" (fig. 4.4.4 and Table 4.4.4)

<u>Table 4.4.1.A</u>. Strontium-90, Cesium-137 and Cesium-134 in sea water collected around Zealand in June 1979, November 1979 and January 1980

	Position		June					November 1979 and January 1980				
	N	E	Depth in m	^{90}Sr pCi l^{-1}	^{137}Cs pCi l^{-1}	^{134}Cs pCi l^{-1}	Salinity o/oo	Depth in m	^{90}Sr pCi l^{-1}	^{137}Cs pCi l^{-1}	^{134}Cs pCi l^{-1}	Salinity o/oo
Kullen	56°15'	12°25'	0	0.53	1.26	0.09	18.1	0	0.66	1.58	0.12	25.7
"			21	0.36	3.34	0.23	32.9	22		2.35	0.15	26.3
Hesselø	56°10'	11°47'	0		0.92	0.07 A	18.1	0	0.58	1.72	0.10	22.9
"			22		3.60	0.22	34.2					
Kattegat SW	56°07'	11°10'	0	0.48	1.08	0.08 A	15.3	0		1.39	0.06	20.0
"			40		3.34	0.18	34.3					
Asnæs rev	55°38'	10°47'	0		1.10	0.08 B	15.3	0		1.27	0.07	18.7
" "			43	1.10	3.35	0.24	32.8					
Halskov rev	55°20'	11°02'	0	0.69	0.96	B.D.L.	13.9	0		0.93	0.04 B	15.5
" "			50		2.81	0.16	32.8					
Langeland bælt	54°52'	10°50'	0		1.31	0.07	16.6					
" "			50		2.56	0.16	30.7					
Femern bælt	54°36'	11°05'	0	0.63	0.87	B.D.L.	13.9	0	0.58	0.96	0.03 B	17.4
" "			27	0.31	2.11	0.14	29.2					
Gedser rev	54°28'	12°13'	0		0.59	B.D.L.	10.4	0		0.64	0.04 B	11.7
" "			25		1.55	B.D.L.	24.3					
Møn	54°57'	12°41'	0	0.63	0.52	B.D.L.	10.3					
"			20		0.80	0.05 B	11.8					
The Sound - South	55°25'	12°39'	0		0.74	B.D.L.	11.7					
" " "			12		1.10	0.06	16.6					
The Sound - North A	55°48'	12°44'	0	0.57	1.27	0.06 B	18.0	0		2.15	0.12	26.2
" " "			19		3.04	0.19	32.2	19	0.60	2.66	0.16	32.0
The Sound - North B	55°59'	12°42'	0		1.09	B.D.L.	17.2	0	0.59	1.75	0.08 A	25.0
" " "			26		2.98	0.18	35.6	25		3.14	0.18	32.0
Mean			Surface	0.62	0.98		14.9		0.60	1.38		20.3
SD				0.06	0.26		2.9		0.04	0.35		5.0
SE				0.03	0.08		0.8		0.02	0.16		1.7
Mean			Bottom	0.59	2.55		29.0		0.60	2.72		30.1
SD				0.44	0.95		7.6			0.40		3.3
SE				0.26	0.27		2.2			0.23		1.9

Table 4.4.1.8. Strontium-90, Cesium-137 and Cesium-134 in sea water collected around Zealand in June 1979, November 1979 and January 1980

	Position		June					November 1979 and January 1980				
	N	E	Depth in m	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	Salinity o/oo	Depth in m	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	Salinity o/oo
Kullen	56°15'	12°25'	0	19.6	47	3.3	18.1	0	24	58	4.4	25.7
"			21	13.3	124	8.5	32.9	22		87	5.6	26.3
Hesselø	56°10'	11°47'	0		34	2.6 A	18.1	0	21	64	3.7	22.9
"			22		133	8.1	34.2					
Kattegat SW	56°07'	11°10'	0	25	40	3.0 A	15.3	0		51	2.2	20.0
"			40		124	6.7	34.3					
Aarhus rev	55°38'	10°47'	0		41	3.0 B	15.3	0		47	2.6	18.7
" "			43	41	124	8.9	32.8					
Halskov rev	55°20'	11°02'	0	26	36	B.D.L.	13.9	0		34	1.5 B	15.5
" "			50		104	5.9	32.8					
Langeland bælt	54°52'	10°50'	0		48	2.6	16.6					
" "			50		95	5.9	30.7					
Femern bælt	54°36'	11°05'	0	23	32	B.D.L.	13.9	0	21	36	1.1 B	17.4
" "			27	11.5	78	5.2	29.2					
Gedser rev	54°28'	12°13'	0		22	B.D.L.	10.4	0		24	1.5 B	11.7
" "			25		57	B.D.L.	24.3					
Møn	54°57'	12°41'	0	23	19.2	B.D.L.	10.3					
"			20		30	1.8 B	11.8					
The Sound - South	55°25'	12°39'	0		27	B.D.L.	11.7					
" " "			12		41	2.2	16.6					
The Sound - North A	55°48'	12°44'	0	21	47	2.2 B	18.0	0		88	4.4	26.2
" " "			19		112	7.0	32.2	19	22	98	5.9	32.0
The Sound - North B	55°59'	12°42'	0		40	B.D.L.	17.2	0	22	65	3.0 A	25.0
" " "			26		110	6.7	35.6	25		116	6.7	32.0
Mean			Surface	23	36		14.9		22	51		20.3
SD				2	10		2.9		1	18		5.0
SE				1	3		0.8		1	6		1.7
Mean			Bottom	22	94		29.0		22	100		30.1
SD				17	35		7.6			15		3.3
SE				10	10		2.2			8		1.9

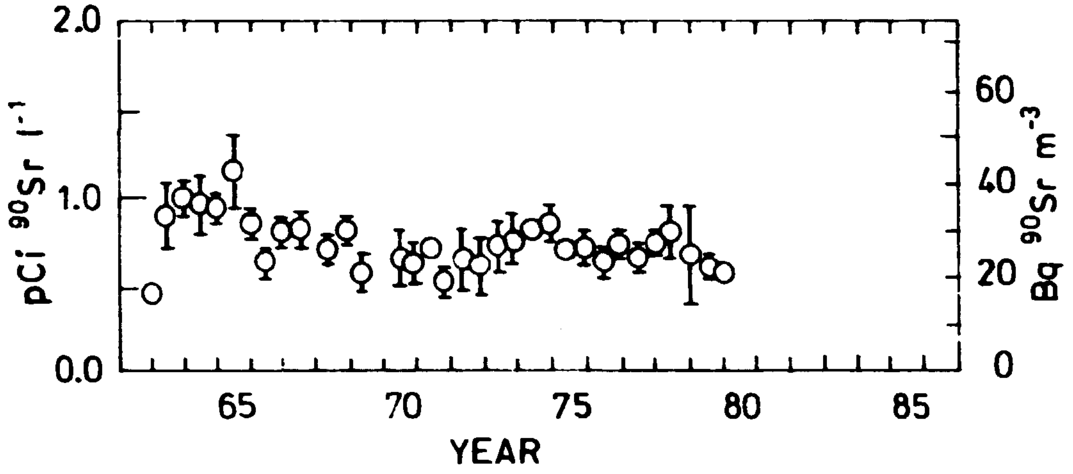


Fig. 4.4.1. Strontium-90 in surface sea water from inner Danish waters, 1962-1979 (1 SD indicated) (from Table 4.4.1).

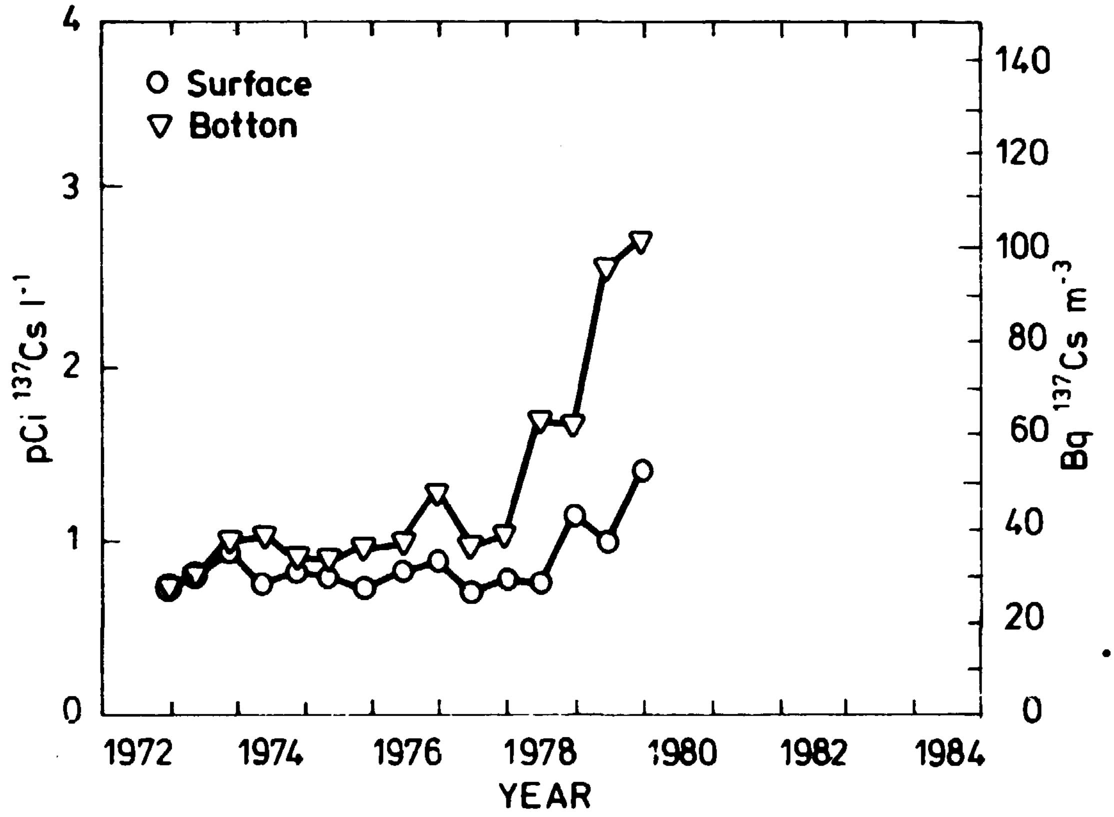


Fig. 4.4.2. Cesium-137 in bottom and surface water collected in inner Danish waters 1972-1979.

Table 4.4.2.A. Strontium-90, Cesium-137 and Cesium-134 in sea water collected in the Sound (Barsebäck) in 1979

Sampling location (cf. Fig. 3.2.1)	Date	Depth in m	^{90}Sr pCi l^{-1}	^{137}Cs pCi l^{-1}	^{134}Cs pCi l^{-1}	Salinity o/oo
Location 33	19/6	0		1.11	B.D.L.	15.3
" "	"	14		2.51	0.15	32.8
Location 34	"	0		1.38	0.08 A	18.2
" "	"	16		2.66	0.14	32.9
Location 35	"	0		1.41	0.08 A	18.1
" "	"	12		2.10	0.13	27.8
Mean	June	Surface		1.30		17.2
S.D.				0.17		1.6
S.E.				0.10		1.0
Mean	June	Bottom		2.42		31.2
S.D.				0.29		2.9
S.E.				0.17		1.7
Location 38	8/12	0	0.49	1.80	0.11	21.6
" "	"	10	0.60	2.08	0.10	26.3
Mean	Dec	Surface	0.49	1.80		21.6
Mean	Dec	Bottom	0.60	2.08		26.3

Table 4.4.2.B. Strontium-90, Cesium-137 and Cesium-134 in sea water collected in the Sound (Barsebäck) in 1979

Sampling location (cf. Fig. 3.2.1)	*Date*	*Depth in m*	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	*Salinity o/oo*
Location 33	19/6	0		41	B.D.L.	15.3
" "	"	14		93	5.6	32.8
Location 34	"	0		51	3.0 A	18.2
" "	"	16		98	5.2	32.9
Location 35	"	0		52	3.0 A	18.1
" "	"	12		78	4.8	27.8
Mean	June	Surface		48		17.2
S.D.				6		1.6
S.E.				4		1.0
Mean	June	Bottom		90		31.2
S.D.				10		2.9
S.E.				6		1.7
Location 38	8/12	0	18.1	67	4.1	21.6
" "	"	10	22.2	77	3.7	26.3
Mean	Dec	Surface	18	67		21.6
Mean	Dec	Bottom	22	77		26.3

<u>Table 4.4.3.A</u>. Strontium-90, Cesium-137 and Cesium-134 in sea water collected at Ringhals in 1979 (cf. also 3.2)

Sampling location (cf. Fig. 3.2.2.)	May				November				
	Depth in m	^{137}Cs pCi l^{-1}	^{134}Cs pCi l^{-1}	Salinity o/oo	Depth in m	^{90}Sr pCi l^{-1}	^{137}Cs pCi l^{-1}	^{134}Cs pCi l^{-1}	Salinity o/oo
0*	0	1.55	0.10 A	21.2	0		1.94	0.11	24.3
-	70	3.81	0.29	35.6	65	0.45	3.30	0.22	36.2
1	0	1.19	0.06 A	19.4					
-	25	3.63	0.23	32.9					
2	0	1.35	0.10 A	19.5	0	0.67	1.78	0.11	23.0
-	24	3.92	0.29	34.2	24	0.48	2.73	0.21	35.6
3	0	1.54	0.13	19.5					
-	17	3.73	0.27	34.2					
15	0	1.31	B.D.L.	19.5					
-	10	1.51	0.09	21.6					
Mean	Surface	1.39		19.8	Surface	0.67	1.86		23.6
S.D.		0.16		0.8			0.11		0.9
S.E.		0.07		0.3			0.08		0.6
Mean	Bottom	3.32		31.7	Bottom	0.46	3.02		35.9
S.D.		1.02		5.7		0.02	0.40		0.4
S.E.		0.46		2.6		0.02	0.28		0.3

*57°14'N 11°53'7"E

<u>Table 4.4.3.B</u>. Strontium-90, Cesium-137 and Cesium-134 in sea water collected at Ringhals in 1979 (cf. also 3.2)

Sampling location (cf. Fig. 3.2.2.)	*May*				*November*				
	Depth in m	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	*Salinity o/oo*	*Depth in m*	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	*Salinity o/oo*
0*	0	57	3.7 A	21.2	0		72	4.1	24.3
-	70	141	10.7	35.6	65	16.6	122	8.1	36.2
1	0	44	2.2 A	19.4					
-	25	134	8.5	32.9					
2	0	50	3.7 A	19.5	0	25	66	4.1	23.0
-	24	145	10.7	34.2	24	17.8	101	7.8	35.6
3	0	57	4.8	19.5					
-	17	138	10.0	34.2					
15	0	48	B.D.L.	19.5					
-	10	56	3.3	21.6					
Mean	*Surface*	51		19.8	*Surface*	25	69		23.6
S.D.		6		0.8			4		0.9
S.E.		3		0.3			3		0.6
Mean	*Bottom*	123		31.7	*Bottom*	17.2	112		35.9
S.D.		38		5.7		0.8	15		0.4
S.E.		17		2.6		0.6	10		0.3

*57°14'N 11°53'7"E

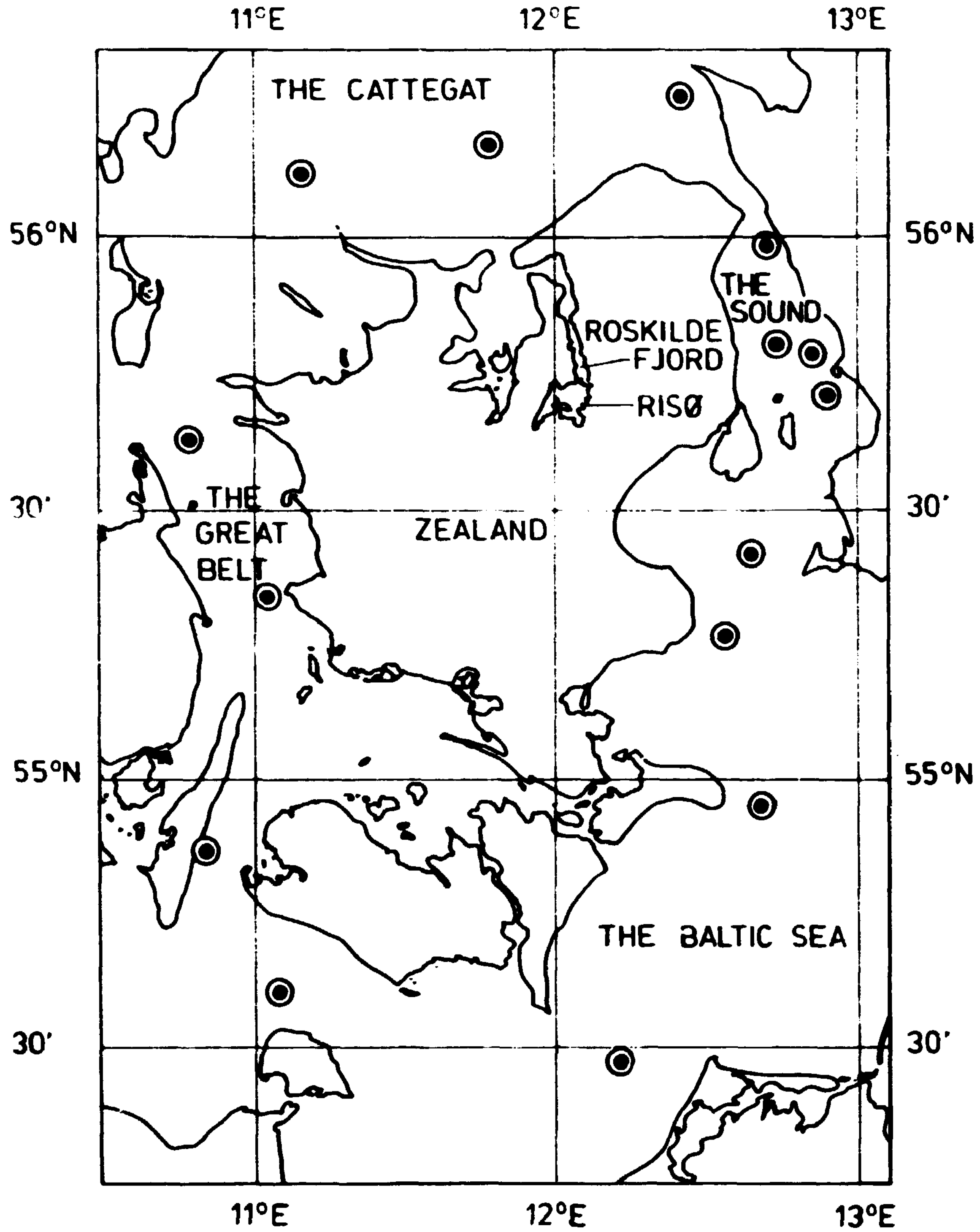


Fig. 4.4.3. Sea water locations around Zealand.

In 1979 ^{134}Cs was detectable in most Danish sea water samples. In order to estimate the age of the ^{134}Cs, which we assume originates from Windscale, we will consider only samples from inner Danish waters collected in May-June with a salinity greater than 30 o/oo. In this water the contribution of fallout ^{137}Cs

Table 4.4.4.A. Strontium-90, Cesium-137 and Cesium-134 in surface sea water collected at the North Sea and Skagerak in 1979

Position N	E	Date	^{90}Sr pCi l^{-1}	^{137}Cs pCi l^{-1}	^{134}Cs pCi l^{-1}	Salinity o/oo	
57°45'	5°30'	21/6		2.86	0.16	30.7	collected by M/S "Nord Jylland"
55°48'	4°30'	28/6		8.35	0.56	35.6	collected by M/S "Nordseen"
57°48,9'	11°17,5'	7/8		3.67	0.26	32.1	collected by M/S "Martin Knudsen"
57°34,5'	9°42'	8/8		4.07	0.25	32.9	
57°07'	8°27'	9/8		3.54	0.22	32.9	
56°14,4'	7°58'	9/8		1.12	0.10	32.8	
55°06,3'	8°16,3'	10/8		1.11	0.11	30.7	
57°41'	10°10'	28/11		0.83	0.07 A	26.0	collected by M/S "Nord Jylland"
55°17'6"	7°07'5"	Dec.	0.49	0.54	0.05 A	35.7	

Table 4.4.4.B. Strontium-90, Cesium-137 and Cesium-134 in surface sea water collected at the North Sea and Skagerak in 1979

Position		Date	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	Salinity o/oo
57°45'N	05°30'E	21/6		106	5.9	30.7
55°48'N	04°30'E	28/6		309	21	35.6
57°48,9'N	11°17,5'E	7/8		136	9.6	32.1
57°34,5'N	09°42'E	8/8		151	9.2	32.9
57°07'N	08°27'E	9/8		131	8.1	32.9
56°14,4'N	07°58'E	9/8		41	3.7	32.8
55°06,3'N	08°16,3'E	10/8		41	4.1	30.7
57°41'N	10°10'E	28/11		31	2.6	26.0
55°17'6"N	07°07'5"E	Dec.	18.1	20	1.8	35.7

is on the order of 5% of the total ^{137}Cs, and may thus be neglected. In other words, the ^{137}Cs in the water with a salinity greater than 30 o/oo is nearly exclusively of Windscale origin, and the ^{134}Cs/^{137}Cs ratios represent the decayed ratios in Windscale releases. We find a mean ^{134}Cs/^{137}Cs ratio equal to 0.063±0.002 (1 SE) (14 determinations). The decay-corrected ratio in Windscale releases from 1976 was 0.066[10]. Hence, we

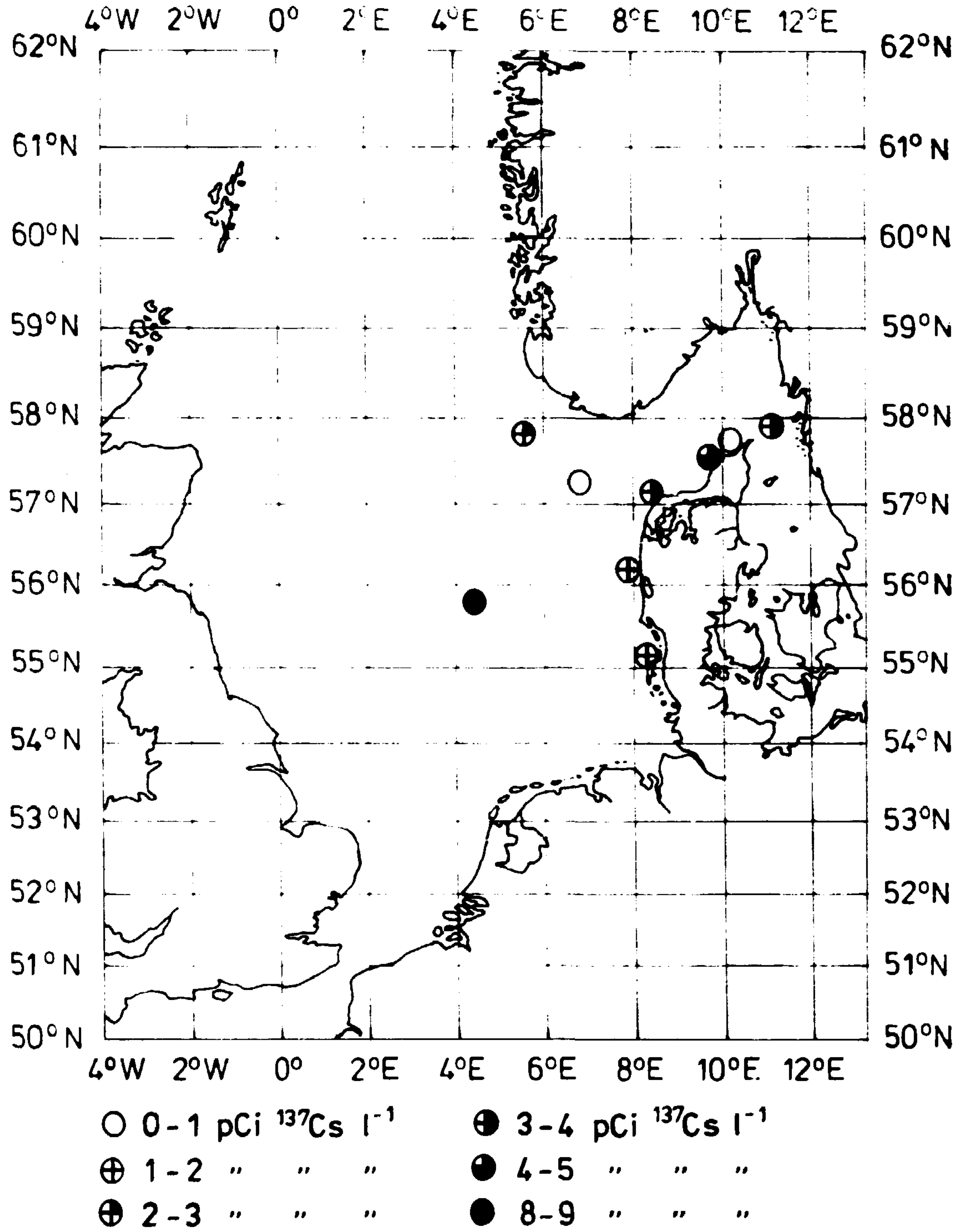
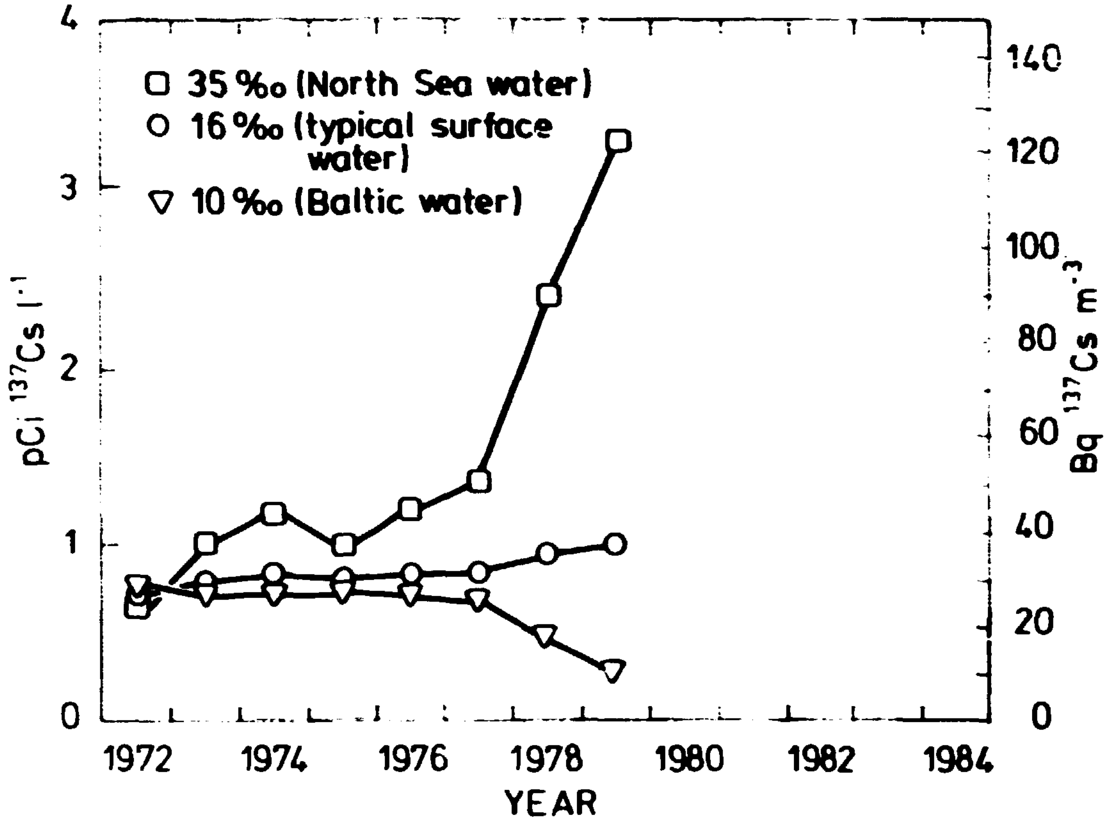
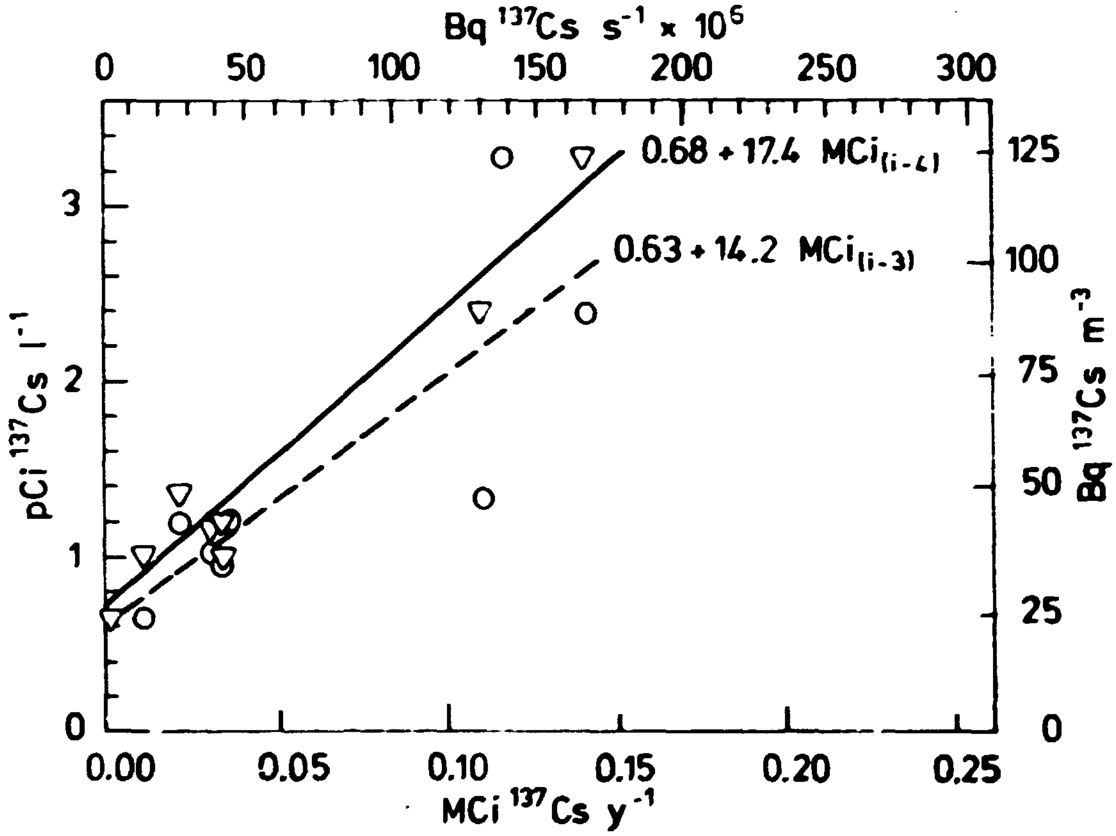


Fig. 4.4.4. Cesium-137 concentrations in surface water collected in the North Sea and Skagerak (cf. table 4.4.4) in 1979.

conclude that our estimate from 1978[1)] of the transport time of Windscale releases to Danish waters of 3 years could not be rejected. However, the decay-corrected $^{134}Cs/^{137}Cs$ for the 1975 release was 0.059, so a transport time of 4 years is also possible. Fig. 4.4.7 shows that the best regression was obtained for a 4-year transport time.



<u>Fig. 4.4.6</u>. Cesium-137 in inner Danish waters of 3 different salinities (1972-1979). The values were calculated from the regression equations in 4.4.



<u>Fig. 4.4.7</u>. Cesium-137 in Danish bottom sea water (salinity 35 o/oo) 1972-1979 as a function of the releases from Windscale 4 years (---- ▽ - -) and 3 years (---- o ----) prior to the sea water sampling.

As was done earlier we calculated the regression equations between salinity and ^{90}Sr and ^{137}Cs activity in the sea water:

$$
\begin{aligned}
&pCi\ ^{90}Sr\ l^{-1} = 0.94 - 0.018\ o/oo\ (1967\text{-}1971)\\
&pCi\ ^{90}Sr\ l^{-1} = 0.97 - 0.020\ o/oo\ (1972)\\
&pCi\ ^{90}Sr\ l^{-1} = 0.95 - 0.014\ o/oo\ (1973)\\
&pCi\ ^{90}Sr\ l^{-1} = 0.93 - 0.010\ o/oo\ (1974)\\
&pCi\ ^{90}Sr\ l^{-1} = 0.79 - 0.006\ o/oo\ (1975)\\
&pCi\ ^{90}Sr\ l^{-1} = 0.71 - 0.002\ o/oo\ (1976)\\
&pCi\ ^{90}Sr\ l^{-1} = 0.71 - 0.0015\ o/oo\ (1977)\\
&pCi\ ^{90}Sr\ l^{-1} = 0.75 - 0.0029\ o/oo\ (1978)\\
&pCi\ ^{90}Sr\ l^{-1} = 0.75 - 0.0083\ o/oo\ (1979)
\end{aligned}
$$

The regression analysis did not show significant or probably significant regression except in 1967-1971, 1972 and in 1974.

$$
\begin{aligned}
&pCi\ ^{137}Cs\ l^{-1} = 0.80 - 0.0043\ o/oo\ (1972)\\
&pCi\ ^{137}Cs\ l^{-1} = 0.60 + 0.012\ o/oo\ (1973)\\
&pCi\ ^{137}Cs\ l^{-1} = 0.54 + 0.018\ o/oo\ (1974)\\
&pCi\ ^{137}Cs\ l^{-1} = 0.64 + 0.010\ o/oo\ (1975)\\
&pCi\ ^{137}Cs\ l^{-1} = 0.53 + 0.019\ o/oo\ (1976)\\
&pCi\ ^{137}Cs\ l^{-1} = 0.41 + 0.027\ o/oo\ (1977)\\
&pCi\ ^{137}Cs\ l^{-1} = -0.28 + 0.077\ o/oo\ (1978)\\
&pCi\ ^{137}Cs\ l^{-1} = -0.90 + 0.120\ o/oo\ (1979)
\end{aligned}
$$

The regression analysis showed significant or probably significant regression in all years except in 1972.

According to the above regression lines, the mean levels in Danish surface waters (16 o/oo salinity) were estimated at 0.62 pCi $^{90}Sr\ l^{-1}$ and 1.02 pCi $^{137}Cs\ l^{-1}$ in 1979. The corresponding levels in North Sea water (34 o/oo) were 0.47 and 3.2, respectively, and in Baltic water (9 o/oo) the equations gave 0.68 and 0.18, respectively (cf. fig. 4.4.6).

4.5. Soil samples

No soil samples were collected in 1979.

4.6. Sediments

4.6.1. Radiocesium in marine sediments collected in "Dybe Rende", the Kattegat

In August 1979 the Marine Pollution Laboratory in Copenhagen collected a HAPS sediment core in "Dybe Rende" ($57^{o}48,9$'N, $11^{o}13$'E) in the Kattegat. The sample was divided into 2-cm thick slices and measured for radiocesium.

Table 4.6.1 shows that ^{137}Cs was detectable all the way down. The 22-24.5-cm layer may have been contaminated by surface material and is therefore excluded.

The presence of ^{134}Cs in the upper 12 cm of the sediment core suggests the presence of "Windscale radiocesium". The expected $^{134}Cs/^{137}Cs$ in this "Windscale radiocesium" may be estimated from the ratios in the Windscale releases and from the transport time from Windscale to Danich waters. The latter was estimated at 3-4 years (cf. 4.4). The activity-weighted estimated $^{134}Cs/^{137}Cs$ ratio becomes 0.05 in August 1979. If this is true, all ^{137}Cs in the upper 6 cm of the sediments is presumed to come from Windscale. In the 6-8 cm layer approximately 89% and in the 8-12 cm layer 60% of ^{137}Cs are from Windscale. If we correct our figures with the contributions from Windscale we estimate the ^{137}Cs fallout in the sediments to be approximately 40 mCi km^{-2}, which is approximately two times higher than generally observed in marine sediments from Danish waters.

4.6.2. Cesium-137 in lake sediments

During the winter, lake sediments were collected from the lakes which are also used for gathering fresh water samples (cf. fig. 4.3.2.1). The samples were collected by the HAPS sampler (used for marine sediments) through a hole in the ice (cf. fig. 4.6.2.1). After the sampling the sediment core was cut into 3-cm thick slices (cf. fig. 4.6.2.2). Table 4.6.2 shows the ^{137}Cs levels in the various layers. There was no correlation between mCi ^{137}Cs km^{-2} in sediments and pCi ^{90}Sr l^{-1} in lake water (cf. Table 4.3.2). The integrated ^{137}Cs levels varied

Table 4.6.1.A. Cesium-137 and Cesium-134 in sediment collected at the position 57°48,9'N 11°13'E in August 1979

Depth in cm	^{137}Cs pCi kg^{-1}	^{137}Cs mCi km^{-2}	^{134}Cs pCi kg^{-1}	^{134}Cs mCi km^{-2}	K g kg^{-1}
0-2	1380	17.2	74 A	0.92 A	20.3
2-4	1370	14.9	65 A	0.71 A	18.7
4-6	1140	11.7	59	0.60	20.0
6-8	1050	11.5	45 A	0.49 A	20.7
8-10	930	8.3	24 B	0.21 B	21.0
10-12	720	8.0	21 B	0.24 B	19.4
12-14	630	7.2	B.D.L.	B.D.L.	19.7
14-16	560	6.4			18.5
16-18	620	7.3			20.2
18-20	490	6.8			19.5
20-22	360	3.8	B.D.L.	B.D.L.	19.2
22-24.5	(330)	(8.1)*			18.9
0-24.5		Σ 103		Σ 3.2	

*Not included in the sum.

Table 4.6.1.B. Cesium-137 and Cesium-134 in sediment collected at the position 57°48,9'N 11°13'E in August 1979

Depth in cm	^{137}Cs Bq kg^{-1}	^{137}Cs Bq m^{-2}	^{134}Cs Bq kg^{-1}	^{134}Cs Bq m^{-2}	kg K kg^{-1}
0-2	51	636	2.7 A	34 A	0.0203
2-4	51	551	2.4 A	26 A	0.0187
4-6	42	433	2.2	22	0.0200
6-8	39	426	1.66 A	18.1 A	0.0207
8-10	34	307	0.89 B	7.8 B	0.0210
10-12	27	296	0.78 B	8.9 B	0.0194
12-14	23	266	B.D.L.	B.D.L.	0.0197
14-16	21	237			0.0185
16-18	23	270			0.0202
18-20	18.1	252			0.0195
20-22	13.3	141	B.D.L.	B.D.L.	0.0192
22-24.5	(12.2)	(300)*			0.0189
0-24.5		Σ 3800		Σ 117	

*Not included in the sum.

Table 4.6.2.A. Cesium-137 in sediment collected in Danish lakes in February 1979

Zones		Depth in cm	^{137}Cs pCi kg^{-1}	^{137}Cs mCi km^{-2}	K g kg^{-1}
I:	North Jutland	0-3	10800	24.07	7.88
	Norsse	3-6	960	4.50	7.41
		6-9	249	1.63	6.09
		9-12	45 A	0.42 A	6.30
		12-15	28 B	0.22 B	5.95
		15-18	17 B	0.15 B	5.81
		18-21	(70)	(0.69)	5.32
Norssø		0-21		Σ 31	
II:	East Jutland	0-3	184	6.10	12.69
	Mossø	3-6	184	7.90	12.34
		6-9	193	7.75	12.01
		9-12	122	5.58	11.99
		12-15	31	1.28	12.01
		15-18	20 A	0.86 A	12.01
		18-21	B.D.L.	B.D.L.	11.73
Mossø		0-21		Σ 29	
III:	West Jutland	0-3	298	11.56	5.56
	Flyndersø	3-6	198	8.20	5.22
		6-9	54	2.56	4.78
		9-12	10.3 B	0.43 B	5.44
		12-15	B.D.L.	B.D.L.	5.65
		15-18	B.D.L.	B.D.L.	4.14
		18-21	(30)	(1.46)	4.09
Flyndersø		0-21		Σ 23	
IV:	South Jutland	0-3	1650	5.25	9.42
	Hostrup sø	3-6	883	2.55	8.35
		6-9	483	0.98	7.39
		9-12	281	0.62	6.74
		12-15	179 A	0.36 A	8.16
		15-18	109 A	0.25 A	6.84
		18-21	162	0.36	7.14
Hostrup sø		0-21		Σ 10.4	
V:	Funen	0-3	2260	6.06	11.95
	Arreskovsø	3-6	1980	5.32	12.74
		6-9	837	2.62	11.60
		9-12	407	1.26	12.94
		12-15	245	0.73	11.59
		15-18	130 A	0.33 A	13.33
		18-21	90 A	0.26 A	12.66
Arreskovsø		0-21		Σ 16.6	
VII:	Lolland-	0-3	740	3.74	9.10
	Falster	3-6	630	2.18	12.66
	Søndersø	6-9	246	0.87	12.55
		9-12	88	0.32	12.66
		12-15	38 A	0.17 B	12.51
		15-18	B.D.L.	B.D.L.	15.26
		18-21	B.D.L.	B.D.L.	14.98
Søndersø		0-21		Σ 7.3	

Table 4.6.2.8. Cesium-137 in sediment collected in Danish lakes in February 1979

Zones		Depth in cm	^{137}Cs Bq kg^{-1}	^{137}Cs Bq m^{-2}	kg K kg^{-1}
I:	North Jutland	0-3	400	891	7.9×10^{-3}
	Norsø	3-6	36	166	7.4×10^{-3}
		6-9	9.2	60	6.1×10^{-3}
		9-12	1.66 A	16 A	6.3×10^{-3}
		12-15	1.04 B	8 B	6.0×10^{-3}
		15-18	0.63 B	6 B	5.8×10^{-3}
		18-21	(2.6)	(26)	5.3×10^{-3}
Norsø		0-21		1150	
II:	East Jutland	0-3	6.8	226	12.7×10^{-3}
	Mossø	3-6	6.8	292	12.3×10^{-3}
		6-9	7.1	287	12.0×10^{-3}
		9-12	4.5	206	12.0×10^{-3}
		12-15	1.15	47	12.0×10^{-3}
		15-18	0.74 A	32 A	12.0×10^{-3}
		18-21	B.D.L.	B.D.L.	11.7×10^{-3}
Mossø		0-21		1090	
III:	West Jutland	0-3	11.0	428	5.6×10^{-3}
	Flyndersø	3-6	7.3	303	5.2×10^{-3}
		6-9	2.0	95	4.8×10^{-3}
		9-12	0.38 B	16 B	5.4×10^{-3}
		12-15	B.D.L.	B.D.L.	5.6×10^{-3}
		15-18	B.D.L.	B.D.L.	4.1×10^{-3}
		18-21	(1.1)	(54)	4.1×10^{-3}
Flyndersø		0-21		840	
IV:	South Jutland	0-3	61	194	9.4×10^{-3}
	Hostrup sø	3-6	33	94	8.4×10^{-3}
		6-9	17.9	36	7.4×10^{-3}
		9-12	10.4	23	6.7×10^{-3}
		12-15	6.6 A	13 A	8.2×10^{-3}
		15-18	4.0 A	9 A	6.8×10^{-3}
		18-21	6.0	13	7.1×10^{-3}
Hostrup sø		0-21		380	
V:	Funen	0-3	84	224	12.0×10^{-3}
	Arreskovsø	3-6	73	197	12.7×10^{-3}
		6-9	31	97	11.6×10^{-3}
		9-12	15.1	47	12.9×10^{-3}
		12-15	9.1	27	11.6×10^{-3}
		15-18	4.8 A	12 A	13.3×10^{-3}
		18-21	3.3 A	10 A	12.7×10^{-3}
Arreskovsø		0-21		610	
VII:	Lolland-Falster	0-3	27	138	9.1×10^{-3}
	Søndersø	3-6	23	81	12.7×10^{-3}
		6-9	9.1	32	12.6×10^{-3}
		9-12	3.3	12	12.7×10^{-3}
		12-15	1.41 A	6 A	12.5×10^{-3}
		15-18	B.D.L.	B.D.L.	12.3×10^{-3}
		18-21	B.D.L.	B.D.L.	15.0×10^{-3}
Søndersø		0-21		270	

between 7 and 31 mCi km^{-2}, i.e. similar to that of marine sediments (Table 3.2.4.1).

The distribution of ^{137}Cs down through the sediment column in Norsso and Mossø differed significantly. In Norssø nearly all the activity was found in the upper 3 cm of the sediments, which may indicate a slow sedimentation rate as well as a low bioturbation, in contrast to Mossø, where the ^{137}Cs was nearly evenly distributed down to 12 cm.

In 1975 and 1976 the ^{137}Cs concentration in lake water from Norssø was measured to 0.17±0.2 (1 SD) pCi $^{137}Cs\ l^{-1}$. From this the K_d value for the upper sediment layer (0-3 cm) was estimated at 6×10^4.Lake water analyses were also available for Flynderso and Hostrup sø and the K_d values for these lakes became 1×10^3 and 4×10^3, respectively. Thus, we may conclude that the sediments in Norssø show a relatively high K_d value for ^{137}Cs.

Fig. 4.6.2.1. The HAPS sediment sampler operated on a pole through a hole in the ice.

Fig. 4.6.2.2. Slicing of lake sediments cores collected by the HAPS.

4.6.3. Sediments from Roskilde Fjord

North of the outlet from the Waste Treatment Station at Risø (fig. 3.1.2.1), marine sediment samples were collected with a HAPS sampler. A core down to a depth of approximately 15 cm was analysed by Ge (γ) spectrometry. Table 4.6.3 shows the results, which were similar to those in previous years, (except 1978)[1]. If we assume bioturbation to be negligible and if the 3-6 cm layer contains the maximum fallout years 1962-1964 the sedimentation rate is in the order of 2-3 mm per year.

Table 4.6.3.A. Cesium-137 in sediment samples collected in Roskilde Fjord in 1979. (HAPS) (145 cm^2)

Depth in cm	Month	pCi ^{137}Cs kg^{-1}	mCi ^{137}Cs km^{-2}
0-15	June	175	27
0-3	Nov	290	8.3
3-6	"	380	10.4
6-9	"	170	5.3
9-12	"	62	2.1
12-14	"	74	1.4
0-14			Σ 28

Table 4.6.3.B. Cesium-137 in sediment samples collected in Roskilde Fjord in 1979. (HAPS) (145 cm^2)

Depth in cm	Month	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs m^{-2}
0-15	June	6.5	1000
0-3	Nov	10.7	310
3-6	"	14.1	380
6-9	"	6.3	196
9-12	"	2.3	78
12-14	"	2.7	52
0-14			Σ 1020

5. DANISH FOOD AND VARIOUS VEGETATION

by A. Aarkrog

5.1. Strontium-90 and Cesium-137 in dried milk from the entire country

As in previous years, monthly samples of dried milk were collected from seven locations in Denmark (cf. fig. 5.1.1). Table 5.1.1 shows the results of the ^{90}Sr determinations and Table

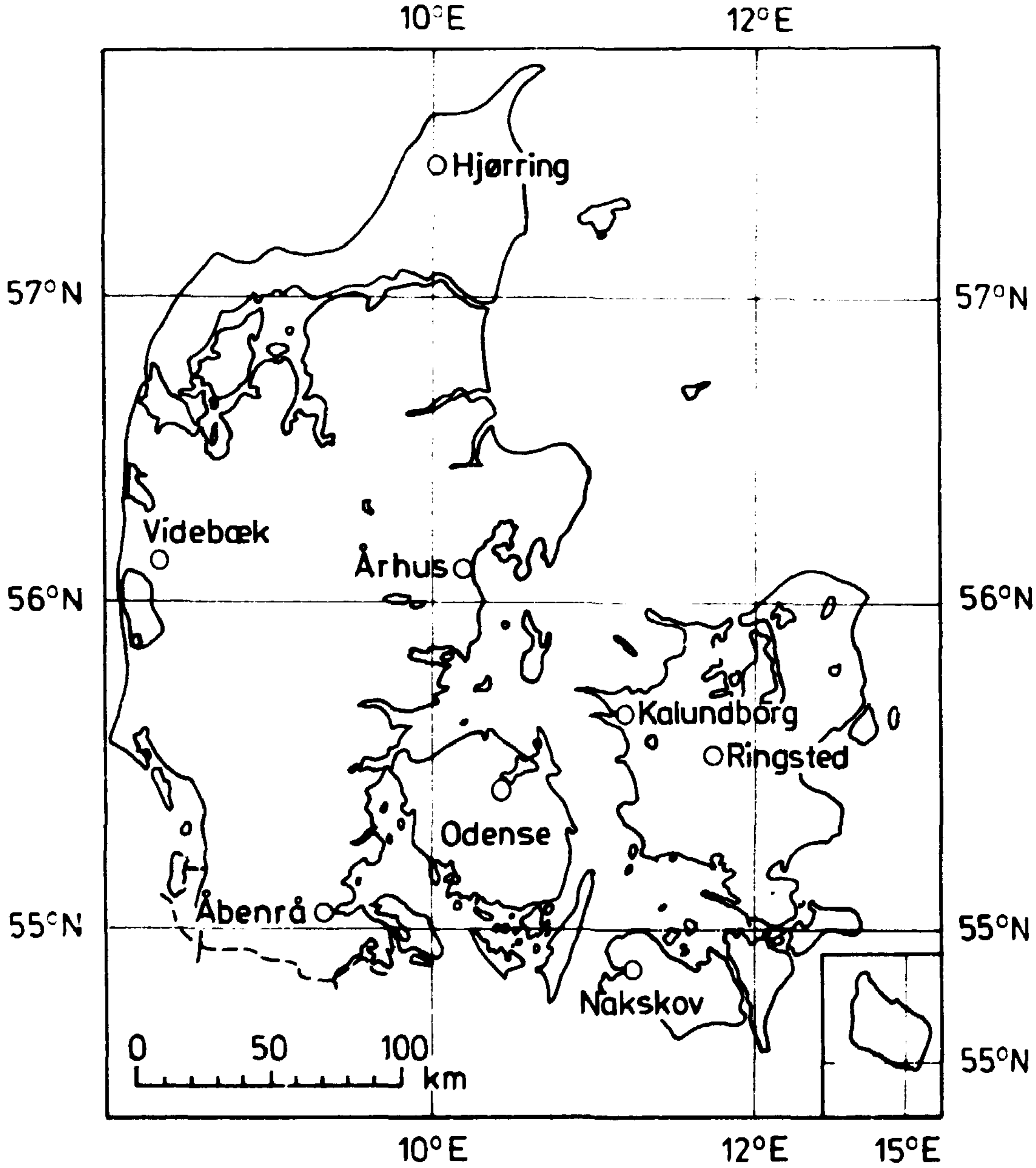


Fig. 5.1.1. Dried milk factories in Denmark.

Table 5.1.1.A. Strontium-90 (pCi (g Ca)$^{-1}$) in Danish dried milk in 1979

Month	Hjørring	Århus	Videbæk	Åbenrå	Odense	Ringsted	Lolland Falster Møn	Mean
Jan	2.8	3.0	3.0	3.2	1.30	2.2	1.82±0.17	2.5
Feb	2.7	2.7	3.0	3.0	1.87	2.6	1.94±0.27	2.5
March	3.5	3.9	5.2	4.4	2.1	(2.9)	1.55	3.4
April	2.9	2.6	4.7	4.1	2.2	3.1	1.94±0.02	3.1
May	3.7	3.0	3.2	4.8	2.6	2.3	2.31±0.32	3.1
June	5.2	3.1	3.8	3.5	4.5	2.9	1.86	3.6
July	3.7	2.8	3.4	4.0	1.95	1.88	1.55	2.8
Aug	2.7	3.7	3.2	3.3	2.1	2.0	1.77±0.16	2.7
Sept	2.8±0.3	2.8±0.5	3.1±0.4	3.0±0.0	2.3±0.9	2.5±0.8	1.50±0.05	2.6
Oct	4.1	4.2	3.4	3.6	2.6	3.9	1.71±0.16	3.4
Nov	3.1	3.2	3.5	3.4	3.1	(2.6)	1.87±0.10	3.0
Dec	2.6	2.7	3.2	3.4	2.8	2.4	2.03	2.7
Mean	3.3	3.1	3.5	3.6	2.4	2.6	1.85	2.9

As 1 litre of milk contains 1.2 g Ca, the mean ^{90}Sr content in Danish milk produced in 1979 was 3.5 pCi l^{-1}. Figures in brackets calculated from VAR3[12]. The error term is 1 S.E. of the mean of double determinations.

Table 5.1.1.B. Strontium-90 (Bq (kg Ca)$^{-1}$) in Danish dried milk in 1979

Month	Hjørring	Århus	Videbæk	Åbenrå	Odense	Ringsted	Lolland Falster Møn	Mean
Jan	102	111	111	118	48	80	67± 6	92
Feb	99	101	111	112	69	96	72±10	92
March	129	143	191	164	76	(107)	72	126
April	106	97	172	152	80	113	72± 1	115
May	138	112	117	176	97	84	85±12	115
June	193	116	140	128	166	108	69	133
July	135	105	125	150	72	70	57	104
Aug	100	135	118	121	77	75	65± 6	100
Sept	102±9	103±19	114±16	110±1	84±33	91±29	56± 2	96
Oct	153	157	124	135	98	145	63± 6	126
Nov	116	120	130	124	115	(96)	69± 4	111
Dec	98	99	119	128	102	87	75	100
Mean	122	115	130	133	89	96	68	107

As 1 cubic-meter of milk contains 1.2 kg Ca, the mean ^{90}Sr content in Danish milk produced in 1979 was 128 Bq m^{-3}. Figures in brackets calculated from VAR 3[12]. The error term is 1 S.E. of the mean of double determinations.

5.1.2 the analysis of variance of the results. As in recent years, the time variation was significant for S.U.; the levels in the second quarter of the year were the highest. The S.U. mean level in 1979 was 2.9 pCi ^{90}Sr (g Ca)$^{-1}$, i.e. 0.9 times the 1978 mean.

As previously, milk from eastern Denmark showed significantly lower levels than that from Jutland.

Table 5.1.2. Analysis of variance of ln pCi ^{90}Sr (g Ca)$^{-1}$ in Danish dried milk in 1979 (from Table 5.1.1.A)

Variation	SSD	f	s^2	v^2	P
Between months	1.211	11	0.110	3.595	> 99.9%
Between locations	5.678	6	0.946	30.895	> 99.95%
Months × locations	1.960	64	0.031	0.519	-
Remainder	0.826	14	0.059		

Table 5.1.3 shows the results of the ^{137}Cs determinations and Table 5.1.4 the analysis of variance of the results. The ^{137}Cs mean level in 1979 was 2.9 pCi ^{137}Cs (g K)$^{-1}$, or 0.7 times the 1978 level.

Figures 5.1.2-5.1.5 show the ^{90}Sr and ^{137}Cs levels in dried milk compared with the predicted values (cf. Appendix C). The observed ^{90}Sr levels in 1979 were 0.97 times the predicted, while the observed ^{137}Cs levels were 1.00 times the predicted ones.

Table 5.1.3.A. Cesium-137 in Danish dried milk in 1979. (Unit: pCi $(g\ K)^{-1}$)

Month	Hjørring	Århus	Videbæk	Åbenrå	Odense	Ringsted	Lolland-Falster Møn	Mean
Jan	3.2	3.1	4.0	4.8	1.74	1.71	2.2	3.0
Feb	4.0	2.9	5.9	3.3	2.2	1.90	2.4	3.2
March	3.2	3.1	4.5	4.1	2.7	1.85	1.94	3.1
April	4.1	2.8	5.2	3.8	2.1	2.5	2.0	3.2
May	3.2	2.6	3.8	3.8	2.1	2.3	2.0	2.8
June	4.3	3.3	4.6	3.6	1.87	1.71	1.98	3.1
July	4.0	2.7	4.6	4.4	1.96	1.98	1.46	3.0
Aug	5.4	5.0	5.6	5.2	1.82	2.2	1.47	3.8
Sept	4.6	4.1	5.8	4.6	1.60	1.70	1.27	3.4
Oct	3.1	3.0	3.8	3.0	2.0	0.98 A	1.04	2.4
Nov	2.5	2.7	3.0	2.4	2.2	(1.41)	2.0	2.3
Dec	2.7	2.2	2.6	2.7	1.37 A	0.82 A	1.28	1.96
Mean	3.7	3.1	4.1	3.8	1.97	1.75	1.75	2.9

As 1 litre of milk contains approx. 1.66 g K, the mean ^{137}Cs content in Danish milk produced in 1979 was estimated at 4.8 pCi l^{-1}. Figures in brackets calculated from VAR3[12].

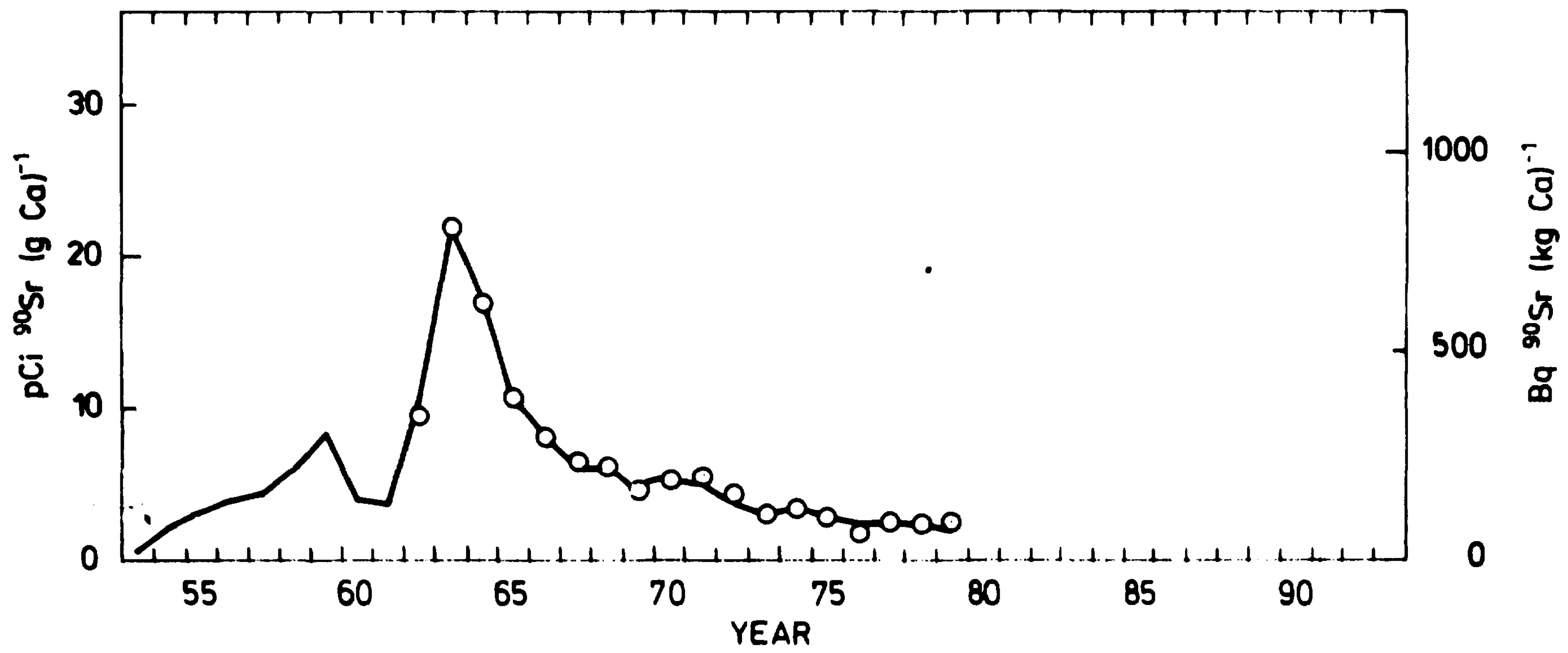
Table 5.1.3.B. Cesium-137 in Danish dried milk in 1979. (Unit: Bq $(kg\ K)^{-1}$)

Month	*Hjørring*	*Århus*	*Videbæk*	*Åbenrå*	*Odense*	*Ringsted*	*Lolland-Falster Møn*	*Mean*
Jan	118	115	148	178	64	63	81	111
Feb	148	107	218	122	81	67	89	118
March	118	115	166	152	100	68	72	115
April	152	104	192	141	78	92	74	118
May	118	96	141	141	78	85	74	104
June	159	122	170	133	69	63	73	115
July	148	100	170	163	73	73	54	111
Aug	200	185	207	192	67	81	54	141
Sept	170	152	215	170	59	63	47	126
Oct	115	111	141	111	74	36	38	89
Nov	92	100	111	89	81	(52)	74	85
Dec	100	81	96	100	51	30	47	73
Mean	137	115	163	141	73	65	65	107

As 1 cubicmeter of milk contains approx. 1.66 kg K, the mean ^{137}Cs content in Danish milk produced in 1979 was estimated at 178 Bq m^{-3}. Figures in brackets calculated from VAR 3[12].

Table 5.1.4. Analysis of variance of ln ^{137}Cs (g K)$^{-1}$ in Danish dried milk (from Table 5.1.3.A)

Variation	SSD	f	s^2	v^2	P
Between months	2.266	11	0.206	5.612	> 99.95%
Between locations	11.500	6	1.917	52.219	> 99.95%
Remainder	2.386	65	0.037		



<u>Fig. 5.1.2</u>. Predicted and observed S.U. levels in dried milk from The Islands (May 1962-April 1980).

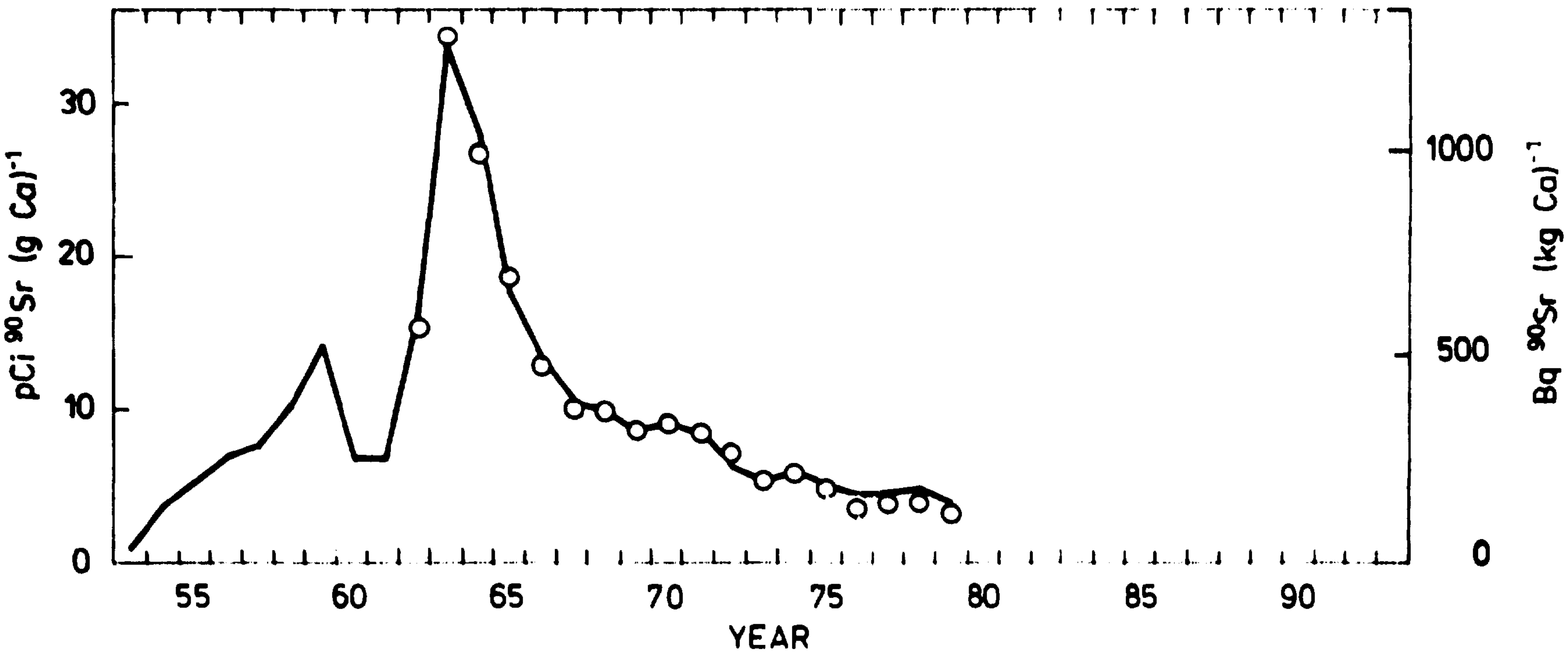


Fig. 5.1.3. Predicted and observed S.U. levels in dried milk from Jutland (May 1962–April 1980).

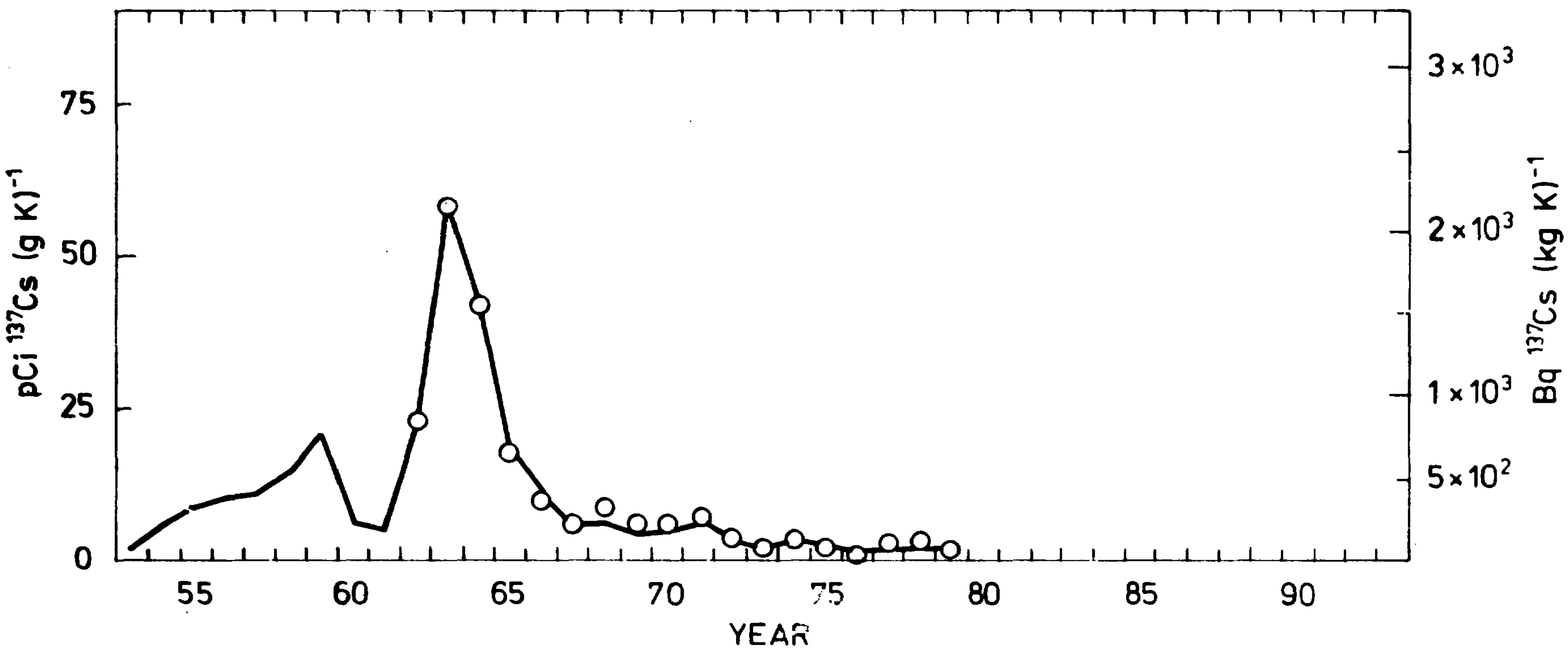


Fig. 5.1.4. Predicted and observed M.U. levels in dried milk from The Islands (May 1962-April 1980).

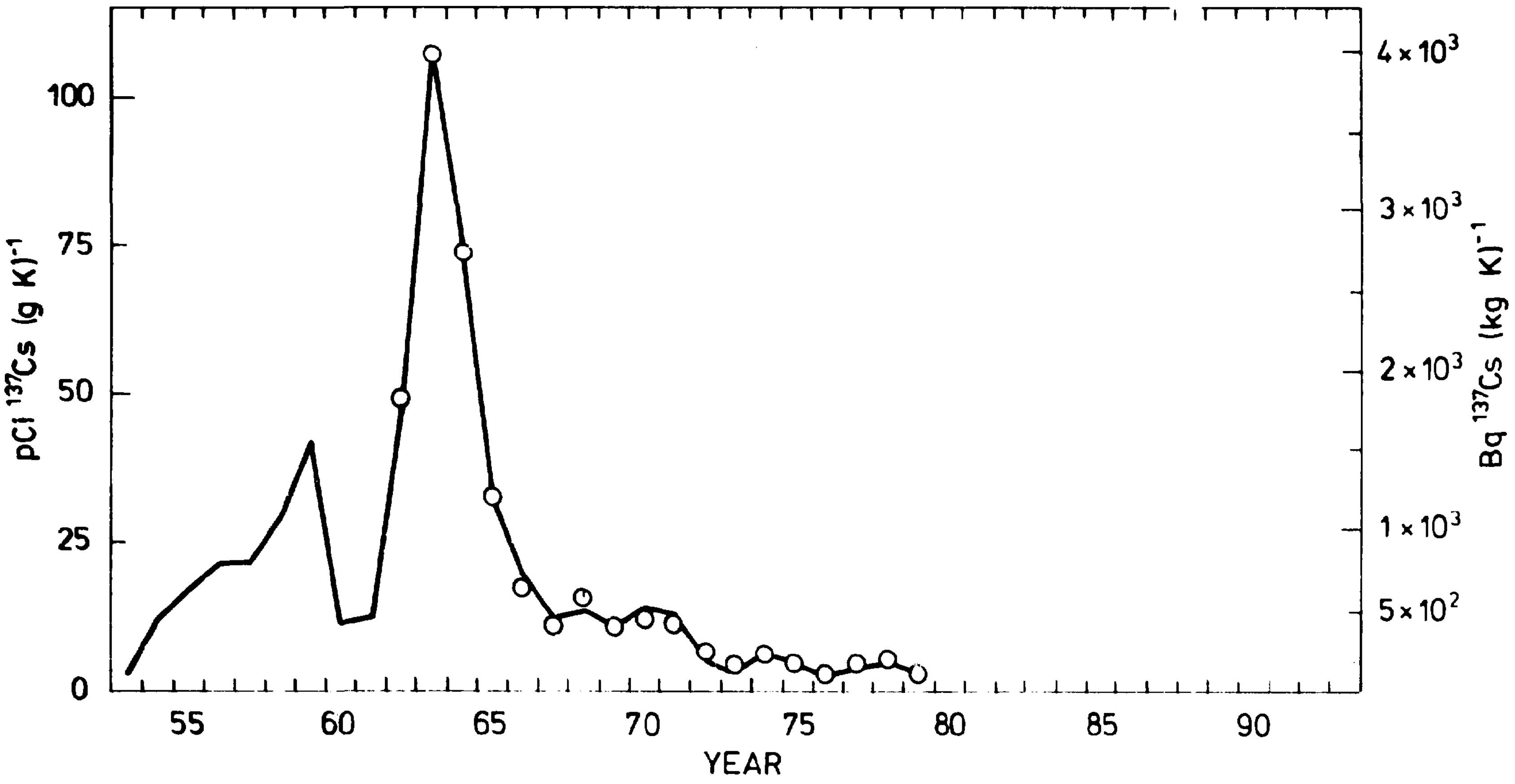


Fig. 5.1.5. Predicted and observed M.U. levels in dried milk from Jutland (May 1962-April 1980).

5.2. Fresh milk

No samples in 1979.

5.3. Strontium-90 and Cesium-137 in grain from the entire country

As in previous years, grain samples were obtained from the State experimental farms (cf. fig. 4.2). Strontium-90 was determined as previously (Risø Report No. 63[1]), and ^{137}Cs was measured on fresh samples by γ-spectrometry on a Ge detector.

Table 5.3.1 shows the measurements of ^{90}Sr in grain in 1979. According to Appendix B, approx. 2/3 of all rye in Denmark is grown in Jutland and 1/3 in the eastern part of the country. As regards wheat, 4/5 is produced in eastern Denmark and 1/5 in Jutland. In the calculation of the means in Tables 5.3.1 and 5.3.4, Jutland is represented by four rye samples and six wheat samples, while eastern Denmark contributes nine wheat and four rye samples. Thus the means in Table 5.3.1 for wheat are higher than the production-weighted means for the country while the mean for rye is lower because the levels in Jutland are higher than those in East Denmark. Table 5.3.2 gives the analysis of variance of the S.U. figures and Table 5.3.3 that of the pCi ^{90}Sr kg^{-1} grain figures.

Table 5.3.2 shows that the variations in S.U. between species and locations were significant. Furthermore, the interaction between species and locations was significant. Rye and wheat showed the highest S.U. levels and oats the lowest. The pCi ^{90}Sr kg^{-1} figures did not show any significant difference between species (cf. Table 5.3.3).

As in previous years, the variation with location was highly significant; the mean pCi ^{90}Sr kg^{-1} level for grain from Jutland was 2.0 times that in eastern Denmark. The observed pCi ^{90}Sr kg^{-1} levels in grain from 1979 were 1.46 times those predicted (cf. Appendix C).

Table 5.3.1.A. Strontium-90 in Danish grain in 1979

	Rye		Barley		Wheat		Oats	
	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{90}Sr kg^{-1}	S.U.
Tylstrup	18.3	55	s:33	s:64	w:22 ±1	w: 41±1	25 ±0	36±0
Borris	21±1	61±0	s:25 ±1 w:32 ±0 s:43**	s:65±4 w:66±2 s:123**	w:32 ±3 s:37 ±2	w:132±12 s: 92± 7	29 ±5	36±6
Ødum			s:24 w:16.5	s:42 w:33	w:14.5	w: 41	17.8	20
Askov	26±2	67±4	s:36 ±0 w:26 ±0*	s:74±0 w:46±2*	w:25 ±1 s:51 ±1	w: 70± 2 s: 73± 1	23 ±2	27±2
St. Jyndevad	34	84	s:30 w:37	s:65 w:80	w: 6.4	w: 23	61	77
Funen	27±1	71±3	s:21 ±2	s:37±2	s:15.2±1.4	s: 42± 4	24 ±1	26±2
Tystofte	13.9	34	s:12.9 w:11.2	s:26 w:16.5	w:19.2 s:11.7	w: 58 s: 29	21	23
Ledreborg	14.0	34	s:16.1 w:10.2	s:61 w:21	w:15.7 s:14.8	w: 48 s: 33	24	24
Abed			s:12.4±1.3	s:24±2	w:11.5±1.6 s:11.4±0.2	w: 35±5 s: 25±0	10.5±0.0	13.1±0.1
Rønne	9.6	25	s: 9.9 w:13.3	s:18.0 w:24	w:15.1 s: 8.8	w: 40 s: 27	9.4	11.5
Mean	20	54	23	49	19.5	51	24	29

* Two different sorts.

**Studsgård.

The error term is 1 S.E. of the mean of double seterminations.

Table 5.3.1.B. Strontium-90 in Danish grain in 1979

	Rye		Barley		Wheat		Oats	
	Bq kg^{-1}	Bq (kg Ca)$^{-1}$	Bq kg^{-1}	Bq (kg Ca)$^{-1}$	Bq kg^{-1}	Bq (kg Ca)$^{-1}$	Bq kg^{-1}	Bq (kg Ca)$^{-1}$
Tylstrup	0.68	2000	s:1.22	s:2400	w:0.81±0.02	w:1510± 40	0.94±0.01	1320± 20
Borris	0.76±0.04	2200± 0	s:0.92±0.03 w:1.19±0.00 s:1.61**	s:2400±100 w:2400±100 s:4600**	w:1.18±0.10 s:1.36±0.08	w:4900±400 s:3100±300	1.06±0.18	1340±220
Ødum			s:0.90 w:0.61	s:1570 w:1220	w:0.54	w:1520	0.66	740
Askov	0.94±0.06	2500±150	s:1.35±0.01 w:0.95±0.01*	s:2700± 0 w:1680± 60*	w:0.91±0.03 s:1.89±0.07	w:2600±100 s:2700±100	0.83±0.07	980± 90
St. Jyndevad	1.25	3100	s:1.11 w:1.38	s:2400 w:3000	w:0.24	w: 850	2.3	2800
Funen	0.98±0.03	2600±100	s:0.77±0.06	s:1360±80	s:0.56±0.05	s:1560±140	0.87±0.05	960± 90
Tystofte	0.52	1270	s:0.48 w:0.41	s: 970 w: 610	w:0.71 s:0.43	w:2100 s:1070	0.78	840
Ledreborg	0.52	1250	s:0.59 w:0.38	s:2200 w: 770	w:0.58 s:0.55	w:1770 s:1230	0.88	880
Abed			s:0.46±0.05	s: 870±90	w:0.42±0.06 s:0.42±0.01	w:1280±190 s: 910± 10	0.39±0.00	480±0
Rønne	0.34	920	s:0.37 w:0.49	s: 670 w: 870	w:0.56 s:0.33	w:1480 s: 780	0.35	430
Mean	0.75	2000	0.84	1820	0.72	1880	0.90	1080

** Two different sorts.*

***Studsgård.*

The error term is 1 S.E. of the mean of double determinations.

Table 5.3.2. Analysis of variance of ln S.U. in grain in 1979 (from Table 5.3.1.A)

Variation	SSD	f	s^2	v^2	P
Between species	4.409	3	1.470	9.348	> 99.95%
Between locations	11.753	9	1.306	8.306	> 99.95%
Spec. x loc.	3.930	25	0.157	2.615	> 99.5%
Remainder	2.285	38	0.060		

Table 5.3.3. Analysis of variance of ln pCi ^{90}Sr kg^{-1} grain in 1979 (from Table 5.3.1.A)

Variation	SSD	f	s^2	v^2	P
Between species	0.197	3	0.066	0.362	-
Between locations	10.306	9	1.145	6.303	> 99.95%
Spec. x loc.	4.542	25	0.182	4.111	> 99.95%
Remainder	1.679	38	0.044		

Table 5.3.4 shows the measurements of ^{137}Cs in grain in 1979. The ^{137}Cs mean level in grain from 1979 was 0.4 times the level in 1978. The fallout in May-August 1979 was also approx. 0.4 times that of the fallout in May-August 1978.

The ANOVA's (Tables 5.3.5 and 5.3.6) showed significant variation between species (rye > the other species) and between locations (Jutland = 1.6 × The Islands).

The observed pCi ^{137}Cs kg^{-1} levels in grain from 1979 were o.86 times those predicted (cf. Appendix C).

Table 5.3.4.A. Cesium-137 in Danish grain in 1979

	Rye		Barley		Wheat		Oats	
	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{137}Cs kg^{-1}	M.U.
Tylstrup	7.4 A	1.66A	s: 7.3 A	s:1.38 A	w: 7.8	w:1.85	7.8	1.76
Borris	14.5	3.4	s:12.5 w:15.2 s:17.4**	s:3.3 w:3.9 s:3.4*	w: 7.3 s:12.4	w:1.69 s:3.2	12.9	2.7
Odum			s: 7.4 w: 9.4	s:1.50 w:2.0	w: 7.6	w:1.86	8.9	1.91
Askov	16.3	3.6	s: 8.8 w:13.6±1.9*	s:1.93 w:3.2±0.5*	w:10.1 s:11.9	w:2.2 s:3.4	14.3	1.94
St. Jyndevad	20.7	4.6	s:10.5 w:16.9	s:2.4 w:3.7	w:13.0	w:3.1	14.0	3.4
Funen	11.9	2.6	s: 7.2	s:1.56	w: 5.4	w:1.34	10.6	2.4
Tystofte	9.0	2.2	s: 8.3 w: 9.5	s:1.88 w:1.67	w: 7.3 s: 9.0	w:2.1 s:2.2	7.9	2.1
Ledreborg	9.1	2.3	s: 7.2 w: 9.3	s:1.61 w:2.00	w: 3.8 A s: 7.4	w:1.08A s:1.85	7.6	2.7
Abed			s: 7.0	s:1.37	w: 4.5 s: 7.3	w:1.17 s:1.81	6.2	1.92
Rønne	8.6	2.2	s: 5.7 w: 5.7	s:1.69 w:1.55	w: 5.6 s: 5.0	w:1.84 s:1.55	5.8	1.94
Mean	12.2	2.8	9.9	2.2	7.8	2.0	9.6	2.3

* Two different sorts.

**Studsgård.

Table 5.3.4.B. Cesium-137 in Danish grain in 1979

	Rye		Barley		Wheat		Oats	
	Bq kg^{-1}	Bq (kg K)$^{-1}$	Bq kg^{-1}	Bq (kg K)$^{-1}$	Bq kg^{-1}	Bq (kg K)$^{-1}$	Bq kg^{-1}	Bq (kg K)$^{-1}$
Tylstrup	0.27 A	61 A	s:0.27 A	s: 51 A	w:0.29	w: 68	0.29	65
Borris	0.54	125	s:0.46 w:0.56 s:0.65**	s:121 w:144 s:126**	w:0.27 s:0.46	w: 63 s:120	0.48	99
Ødum			s:0.27 w:0.35	s: 56 w: 74	w:0.28	w: 69	0.33	71
Askov	0.60	135	s:0.33 w:0.50±0.07*	s: 71 w:118±20*	w:0.37 s:0.44	w: 82 s:125	0.53	72
St. Jyndevad	0.76	171	s:0.39 w:0.62	s: 91 w:137	w:0.48	w:115	0.52	125
Funen	0.44	97	s:0.27	s: 58	w:0.20	w: 50	0.39	89
Tystofte	0.33	83	s:0.31 w:0.35	s: 70 w: 62	w:0.27 s:0.33	w: 77 s: 80	0.29	79
Ledreborg	0.34	84	s:0.27 w:0.34	s: 60 w: 74	w:0.141A s:0.27	w: 40 A s: 68	0.28	101
Abed			s:0.26	s: 51	w:0.168 s:0.27	w: 43 s: 67	0.23	71
Rønne	0.32	80	s:0.21 w:0.2[illegible]	s: 63 w: 57	w:0.21 s:0.186	w: 68 s: 57	0.21	72
Mean	0.45	104	0.37	82	0.29	74	0.36	84

* Two different sorts.

**Studsgård.

<u>Table 5.3.5.</u> Analysis of variance of ln pCi ^{137}Cs (g K)$^{-1}$ in grain in 1979 (from Table 5.3.4.A)

Variation	SSD	f	s^2	v^2	P
Between species	0.533	3	0.178	4.740	> 99%
Between locations	3.310	9	0.368	9.809	> 99.95%
Spec. x loc.	0.937	25	0.037	0.594	-
Remainder	0.947	15	0.063		

<u>Table 5.3.6.</u> Analysis of variance of ln pCi ^{137}Cs kg^{-1} grain in 1979 (from Table 5.3.4.A)

Variation	SSD	f	s^2	v^2	P
Between species	0.819	3	0.273	10.978	> 99.95%
Between locations	4.501	9	0.506	20.105	> 99.95%
Spec. x loc.	0.622	25	0.025	0.408	-
Remainder	0.915	15	0.061		

<u>Table 5.4.1.A.</u> Strontium-90 and Cesium-137 in Danish bread collected in June 1979

Location	Rye bread				White bread			
	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.
Jutland	13.0±0.2	4.6±0.1	23	9.6	4.6±0.1	2.3±0.1	6.9	4.2
The Islands	16.1±0.0	5.8±0.0	24	8.8	4.1±0.2	2.1±0.1	6.5	4.7
Mean	14.6	5.2	23	9.2	4.4	2.2	6.7	4.4
Copenhagen	18.4±0.3	9.7±0.1	29	8.6	3.6±0.0	2.0±0.0	4.6	2.8
Population-weighted mean	15.4	6.[illegible]	25	9.1	4.2	2.2	6.2	4.0

<u>*Table 5.4.1.B.*</u> *Strontium-90 and Cesium-137 in Danish bread collected in June 1979*

Location	Rye bread				White bread			
	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
Jutland	0.48±0.01	170±4	0.85	360	0.170±0.004	85±4	0.26	155
The Islands	0.60±0.00	210±0	0.89	330	0.152±0.007	78±4	0.24	174
Mean	0.54	190	0.87	340	0.165	81	0.25	163
Copenhagen	0.68±0.01	360±0	1.07	320	0.133±0.000	74±0	0.170	104
Population-weighted mean	0.57	230	0.92	340	0.155	81	0.23	148

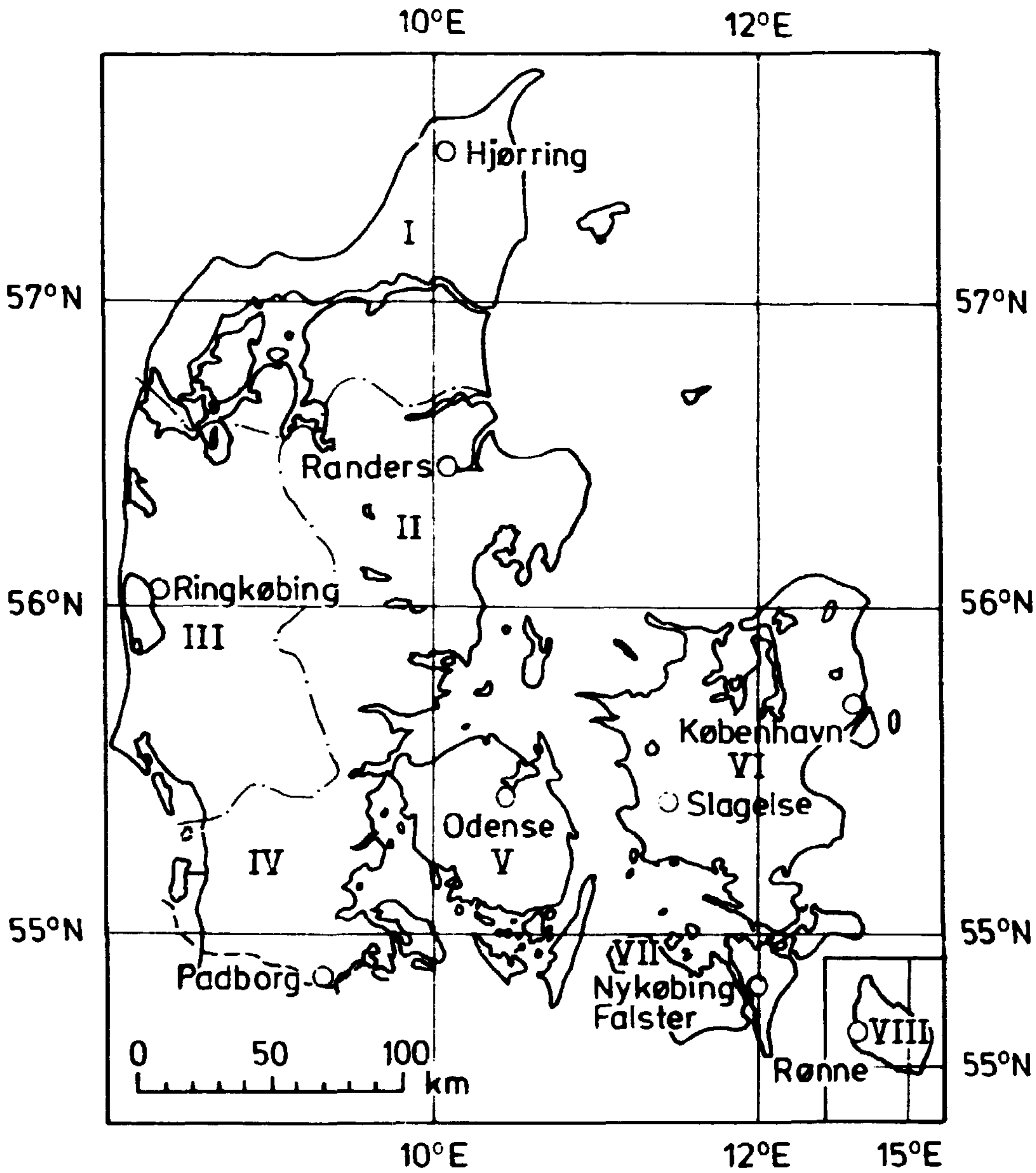


Fig. 5.4. Sample locations for bread and total diet.

5.4. Strontium-90 and Cesium-137 in bread from the entire country

In 1979, samples of white bread (75% extraction) and dark rye bread (100% extraction) were collected all over the country (cf. fig. 5.4) in June, and ^{90}Sr and ^{137}Cs were determined on pooled samples. The ^{137}Cs determinations were carried out on the ash by Ge γ-spectroscopy.

Table 5.4.2. A comparison between ^{90}Sr and ^{137}Cs levels in bread and grain in 1979

Nuclide	Species	Bread activity in June 1979 calculated as grain in pCi kg^{-1} (cf. text)	Activity in grain from harvest 1978[1] pCi kg^{-1}	"Bread"/grain ratio
^{90}Sr	Wheat	28	25	1.1
	Rye	21	23	0.9
^{137}Cs	Wheat	16.7	20	0.8
	Rye	34	40	0.8

Table 5.4.1 shows the results. It is assumed that 1 kg flour yields approx. 1.35 kg bread[11] and that wheat flour of 75% extraction contains 20% of the ^{90}Sr and 50% of the ^{137}Cs found in wheat grain[1], while rye flour is 100% extraction. Hence we can compare the 1979 bread levels with the 1978 grain levels (cf. Table 5.4.2).

5.5. Strontium-90 and Cesium-137 in potatoes from the entire country

The samples of potatoes were collected in September from eleven of the State experimental farms (cf. fig. 4.2) and analysed for ^{90}Sr and ^{137}Cs (γ-spectroscopy of bulked samples of the ash).

Table 5.5.1 shows the ^{90}Sr and ^{137}Cs contents in potatoes. The mean contents for the country were 2.0 pCi ^{90}Sr kg^{-1}, or 53 pCi ^{90}Sr $(g\ Ca)^{-1}$, and 2.1 pCi ^{137}Cs kg^{-1} or 0.5 pCi ^{137}Cs $(g\ K)^{-1}$. The ^{90}Sr levels were equal to those in 1978, while the ^{137}Cs concentrations were 1.8 times lower. In case of potatoes we see no significant difference between the ^{90}Sr levels in Jutland and the Islands.

Table 5.5.1.A. Strontium-90 and Cesium-137 in Danish potatoes in 1979

	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.
Tylstrup	2.3 ±0.2	88±10		
Studsgård	0.92±0.06	42±3		
Borris	1.20±0.03	39±1		
Ødum	2.1 ±0.0	46±0	2.7	0.68
Askov	2.2 ±0.0	73±0		
St. Jyndevad	1.50±0.04	50±0		
Fanen	2.1 ±0.1	53±5		
Tystofte	2.6 ±0.2	37±2		
Ledreborg	3.2 ±0.3	46±4	1.5	0.36
Abed	1.13±0.09	19.4±1.9		
Rønne	2.2 ±0.0	85±3		
Mean	2.0	53	2.1	0.52

The error term is 1 S.E. of the mean of double determinations.

Table 5.5.1.B. Strontium-90 and Cesium-137 in Danish potatoes in 1979

	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$
Tylstrup	0.104±0.007	3300±100		
Studsgård	0.034±0.002	1550±110		
Borris	0.044±0.001	1440± 40		
Ødum	0.078±0.000	1700± 0	0.100	25
Askov	0.081±0.000	2700± 0		
St. Jyndevad	0.056±0.001	1850± 0		
Fanen	0.078±0.004	1960±180		
Tystofte	0.096±0.007	1370± 70		
Ledreborg	0.118±0.011	1700±150	0.056	13.3
Abed	0.042±0.003	720± 70		
Rønne	0.081±0.000	3100±100		
Mean	0.074	1950	0.078	19.2

The error term is 1 S.E. of the mean of double determinations.

5.6. Strontium-90 and Cesium-137 in vegetables and fruit from the entire country

In 1979, as in previous years, vegetables and fruit were collected in the autumn from eight larger provincial towns, one in each of the eight zones (cf. fig. 5.4).

The γ-measurements were performed on bulked ash samples representing the entire country (cf. Table 5.6.2).

Table 5.6.1.A. Strontium-90 in vegetables and fruits collected in August 1979

	Cabbage		Carrot		Apples	
	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{90}Sr kg^{-1}	S.U.
Jutland	12.2±0.5	42 ±2	9.8±0.2*	40±2*	0.61±0.05	18.1±0.6
The Islands + Copenhagen	6.2±0.4	15.1±0.2	6.4±0.2*	23±1*	0.42±0.02	10.3±1.5
Mean	9.2	29	8.1	32	0.52	14.2
Population-weighted mean	8.9	27	8.0	31	0.51	13.8

*Triple determinations.

The error term is 1 S.E. of the mean of double determinations.

Table 5.6.1.B. Strontium-90 in vegetables and fruits collected in August 1979

	Cabbage		Carrot		Apples	
	Bq kg^{-1}	Bq (kg Ca)$^{-1}$	Bq kg^{-1}	Bq (kg Ca)$^{-1}$	Bq kg^{-1}	Bq (kg Ca)$^{-1}$
Jutland	0.45	1550	0.36	1480	0.023	670
The Islands + Copenhagen	0.23	560	0.24	850	0.016	380
Mean	0.34	1070	0.30	1180	0.019	530
Population-weighted mean	0.33	1000	0.30	1150	0.019	510

Table 5.6.2.A. Cesium-137 in Danish vegetables and fruits in August 1979

	Cabbage		Carrot		Apples	
	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{137}Cs kg^{-1}	M.U.
Jutland	3.6	1.72	1.34 A	0.85 A	2.0	1.74
The Islands + Copenhagen	0.82 A	0.36 A	0.75 A	0.38 A	1.73	1.48
Mean	2.2	1.04	1.05	0.62	1.87	1.61
Population-weighted mean	2.1	0.97	1.02	0.59	1.86	1.60

Table 5.6.2.B. Cesium-137 in Danish vegetables and fruits in August 1979

	Cabbage		Carrot		Apples	
	Bq kg^{-1}	Bq (kg K)$^{-1}$	Bq kg^{-1}	Bq (kg K)$^{-1}$	Bq kg^{-1}	Bq (kg K)$^{-1}$
Jutland	0.133	64	0.050 A	31 A	0.074	64
The Islands + Copenhagen	0.030 A	13.3 A	0.028 A	14.1 A	0.064	55
Mean	0.081	38	0.039	23	0.069	60
Population-weighted mean	0.078	36	0.038	22	0.069	59

Table 5.6.3 shows a calculation of the mean contents of ^{90}Sr and ^{137}Cs in Danish vegetables collected in 1979. The levels are the population-weighted means and are nearly unchanged from 1978 suggesting that most of the activity in vegetables depends upon the accumulated activity in the soil.

The 1979 levels in Danish fruit were calculated from apples and the mean levels in Danish fruit were thus 0.5 pCi ^{90}Sr kg^{-1} and 1.9 pCi ^{137}Cs kg^{-1}. The observed pCi ^{90}Sr kg^{-1} levels in vegetables and fruit in 1979 were 0.89 times those predicted (cf. Appendix C). In the case of ^{137}Cs, the observed values were 1.02 times the predicted ones.

Table 5.6.3.A. Calculated ^{90}Sr and ^{137}Cs mean levels in vegetables in 1979

Daily intake in g	Species	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.
50	Leaf vegetables (cabbage)	8.9	27	2.1	0.97
30	Root vegetables (carrot)	8.0	31	1.02	0.59
40	Pea (1977 data)	3.6	12	1.6	0.1
120	Vegetables total	6.9	23	1.7	0.59

Table 5.6.3.B. Calculated ^{90}Sr and ^{137}Cs mean levels in vegetables in 1979

Daily intake in g	Species	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$
50	Leaf vegetables (cabbage)	0.33	1000	0.078	36
30	Root vegetables (carrot)	0.30	1150	0.038	22
40	Pea (1977 data)	0.13	440	0.059	4
120	Vegetables total	0.26	[illegible]50	0.062	22

5.7. Strontium-90 and Cesium-137 in total diet from the entire country

In 1979 total-food samples representing an average Danish diet according to E. Hoff-Jørgensen (cf. Appendix B in Risø Report No. 63[1]) were collected from eight towns each representing one of the eight zones (cf. fig. 5.2.1) and from Copenhagen. The sampling took place as previously in June and December.

Tables 5.7.1 and 5.7.2 show the results. The diet levels from Jutland were 18% higher than those from the Islands.

Figure 5.7.1 show the zone mean S.U. levels (not population-weighted) in total diet compared with the predicted values (cf. Appendix C), the obs[illegible] value was 0.83 times that predicted.

Table 5.7.1.A. Strontium-90 and Cesium-137 in Danish total diet collected in June 1979

Zone		pCi ^{90}Sr (g Ca)$^{-1}$	pCi ^{90}Sr day^{-1}	g Ca day^{-1}	pCi ^{137}Cs (g K)$^{-1}$	pCi ^{137}Cs day^{-1}
I:	N. Jutland	5.1±0.3	8.1±0.5	1.59±0.06	3.1	11.9
II:	E. Jutland	4.5±0.0	7.3±0.1	1.62±0.02	3.2	12.4
III:	W. Jutland	5.4±0.1	8.2±0.1	1.50±0.00	4.1	15.7
IV:	S. Jutland	4.4±0.3	7.5±0.5	1.70±0.01	3.2	13.0
V:	Funen	4.1±0.1	6.8±0.1	1.64±0.00	3.0	11.3
VI:	Zealand	3.9±0.0	6.1±0.0	1.55±0.01	2.9	11.6
VII:	Lolland-Falster	4.3±0.2	8.2±0.4	1.90±0.00	3.5	13.6
VIII:	Bornholm	4.5±0.1	7.1±0.1	1.57±0.01	3.0	12.6
Mean		4.5	7.4	1.63	3.2	12.8
Copenhagen		5.0±0.2	8.1±0.4	1.63±0.00	3.0	11.7
Population-weighted mean		4.7	7.5	1.61	3.2	12.5
Relative error due to analysis		6%	6%	1%		

The error term is 1 S.E. of the mean of double determinations.

Table 5.7.1.B. Strontium-90 and Cesium-137 in Danish total diet collected in June 1979

Zone		Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{90}Sr s^{-1}	kg Ca s^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{137}Cs s^{-1}
I:	N. Jutland	189	3.5×10^{-6}	18.4×10^{-9}	115	5.1×10^{-6}
II:	E. Jutland	166	3.1×10^{-6}	18.8×10^{-9}	118	5.3×10^{-6}
III:	W. Jutland	200	3.5×10^{-6}	17.4×10^{-9}	152	6.7×10^{-6}
IV:	S. Jutland	163	3.2×10^{-6}	19.7×10^{-9}	118	5.6×10^{-6}
V:	Funen	152	2.9×10^{-6}	19.0×10^{-9}	111	4.8×10^{-6}
VI:	Zealand	144	2.6×10^{-6}	17.9×10^{-9}	107	5.0×10^{-6}
VII:	Lolland-Falster	159	3.5×10^{-6}	22.0×10^{-9}	130	5.8×10^{-6}
VIII:	Bornholm	166	3.0×10^{-6}	18.2×10^{-9}	111	5.4×10^{-6}
Mean		166	3.2×10^{-6}	18.9×10^{-9}	118	5.5×10^{-6}
Copenhagen		185	3.5×10^{-6}	18.9×10^{-9}	111	5.0×10^{-6}
Population-weighted mean		174	3.2×10^{-6}	18.6×10^{-9}	118	5.4×10^{-6}
Relative error due to analysis		6%	6%	1%		

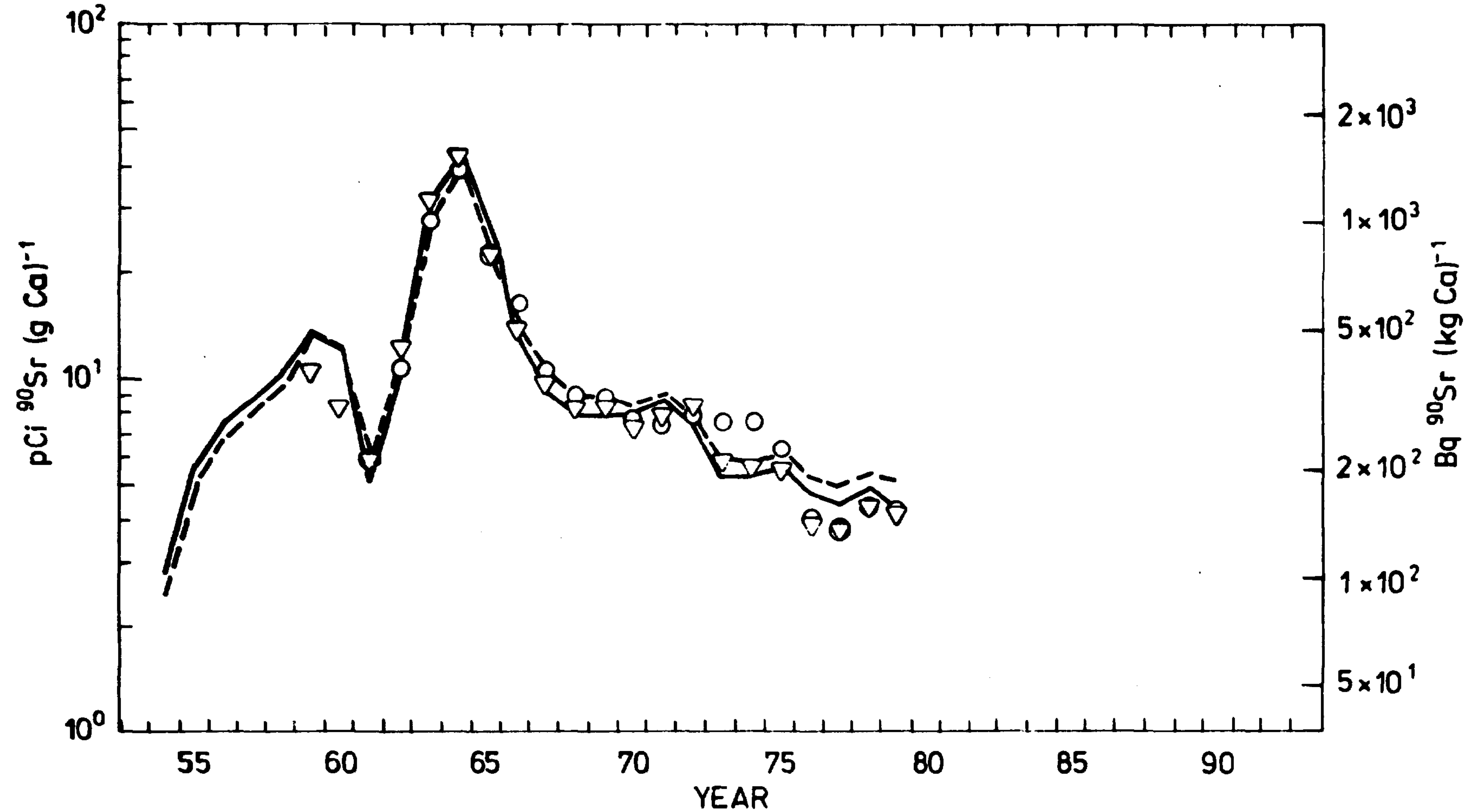
Table 5.7.2.A. Strontium-90 and Cesium-137 in Danish total diet collected in December 1979

Zone		pCi ^{90}Sr (g Ca)$^{-1}$	pCi ^{90}Sr day^{-1}	g Ca day^{-1}	pCi ^{137}Cs (g K)$^{-1}$	pCi ^{137}Cs day^{-1}
I:	N. Jutland	4.7±0.0	7.7±0.1	1.63±0.00	2.8	12.4
II:	E. Jutland	4.5±0.3	7.4±0.4	1.65±0.02	2.6	11.0
III:	W. Jutland	4.6±0.4	7.1±0.5	1.54±0.00	3.1	13.5
IV:	S. Jutland	4.1±0.0	6.7±0.1	1.65±0.00	2.4	1[illegible]
V:	Funen	3.7±0.1	6.7±0.2	1.82±0.00	2.3	9.3
VI:	Zealand	3.8±0.0	6.6±0.0	1.72±0.00	2.7	11.0
VII:	Lolland-Falster	3.3±0.1	5.8±0.1	1.78±0.00	1.79	7.4
VIII:	Bornholm	4.1±0.1	6.5±0.2	1.58±0.01	1.76	7.7
Mean		4.1	6.8	1.67	2.4	10.3
Copenhagen		3.4±0.0	5.4±0.0	1.58±0.01	2.4	10.5
Population-weighted mean		4.0	6.6	1.65	2.6	11.1
Relative error due to analysis		6%	5%	1%		

The error term is 1 S.E. of the mean of double determinations.

Table 5.7.2.B. Strontium-90 and Cesium-137 in Danish total diet collected in December 1979

Zone		Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{90}Sr s^{-1}	kg Ca s^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{137}Cs s^{-1}
I:	N. Jutland	174	3.3×10^{-6}	18.5×10^{-9}	104	5.3×10^{-6}
II:	E. Jutland	166	3.2×10^{-6}	19.1×10^{-9}	96	4.7×10^{-6}
III:	W. Jutland	170	3.0×10^{-6}	17.8×10^{-9}	115	5.8×10^{-6}
IV:	S. Jutland	152	2.9×10^{-6}	19.1×10^{-9}	89	4.4×10^{-6}
V:	Funen	137	2.9×10^{-6}	21.1×10^{-9}	85	4.0×10^{-6}
VI:	Zealand	141	2.8×10^{-6}	19.9×10^{-9}	100	4.7×10^{-6}
VII:	Lolland-Falster	122	2.5×10^{-6}	20.6×10^{-9}	66	3.2×10^{-6}
VIII:	Bornholm	152	2.8×10^{-6}	18.3×10^{-9}	65	3.3×10^{-6}
Mean		152	2.9×10^{-6}	19.3×10^{-9}	89	4.4×10^{-6}
Copenhagen		126	2.3×10^{-6}	18.3×10^{-9}	89	4.5×10^{-6}
Population-weighted mean		148	2.8×10^{-6}	19.1×10^{-9}	96	4.8×10^{-6}
Relative error due to analysis		6%	5%	1%		



<u>**Fig. 5.7.1**</u>. Predicted and observed ^{90}Sr levels in the Danish total diet. The dotted curve represents the predicted values for "Diet C" (cf. Tables 5.7.1 and 5.7.2) and the circles are the corresponding observed values. The unbroken curve represents the predicted values for "Diet P" (cf. Table 5.9.3), and the triangles the corresponding observed values.

The ^{90}Sr 1979 levels in the total diet were nearly equal to the 1978 levels, and the ^{137}Cs levels were approx. 15% lower.

From the total-diet sampling it is possible to estimate the mean levels of ^{90}Sr and ^{137}Cs in the Danish diet in 1979. For the period January-March 1979, the ^{90}Sr level in the total diet is assumed to have been equal to that measured in December 1978, Risø Report No. 403[1)]. For the period April-September we assume the level to have corresponded to that measured in June 1979. The December 1979 figures are taken to represent the last three months of the year. The population-weighted mean of ^{90}Sr in total-diet samples was 3.9 pCi ^{90}Sr (g Ca)$^{-1}$ in December 1978. Hence the mean content in the total diet in 1979 was 4.3 pCi ^{90}Sr (g Ca)$^{-1}$, or 7.1 pCi ^{90}Sr (day)$^{-1}$.

Similarly, the ^{137}Cs content in the Danish diet in 1979 was estimated to be 13.0 pCi ^{137}Cs (day)$^{-1}$ or 3.3 pCi ^{137}Cs (g K)$^{-1}$. The observed ^{137}Cs level in total diet was 0.89 times that predicted (cf. Appendix C.2).

5.8. Strontium-90 and Cesium-137 in miscellaneous foodstuffs

5.8.1. Strontium-90 and Cesium-137 in meat

Pork and beef samples were collected in Copenhagen in three large shops in June and December. Table 5.8.1 shows the results. As compared with 1978, the mean ^{137}Cs levels were lower in 1979.

Table 5.8.1.A. Strontium-90 and Cesium-137 in Danish meat collected in Copenhagen in 1979

Month	Pork				Beef			
	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.
June			25	6.3	0.52	7.5	9.2	2.6
December	1.43	23	17.0	4.9	0.15	5.4	11.5	3.1
Mean	1.43	23	21	5.6	0.34	6.4	10.4	2.8

Table 5.8.1.B. *Strontium-90 and Cesium-137 in Danish meat collected in Copenhagen in 1979*

Month	Pork				Beef			
	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$
June			0.92	2[illegible]0	0.019	280	0.34	96
December	0.053	850	0.63	181	0.006	200	0.43	115
Mean	0.053	850	0.78	210	0.013	240	0.38	104

The mean ratio between observed and predicted (cf. Appendix C.2) ^{137}Cs levels in meat was 0.81.

5.8.2. Strontium-90 and Cesium-137 in fish

Fish samples were collected in the North Sea and in inner Danish waters. Tables 5.8.2.1 and 5.8.2.2 show the results. The mean levels of the two samplings were 2 pCi ^{90}Sr kg^{-1} and 104 pCi ^{137}Cs kg^{-1}. In the fish from the North Sea the ^{134}Cs/^{137}Cs ratio was 0.06 while it was less than 0.04 for fish from inner Danish waters.

Table 5.8.2.1.A. Strontium-90, Cesium-137 and Cesium-134 in fish meat from the North Sea purchased in Esbjerg in August 1979

Species	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{134}Cs kg^{-1}
Cod	0.24 B	0.30 B	174	40	10.2
Plaice	0.54	0.86	75	19.2	4.6

Table 5.8.2.1.B. *Strontium-90, Cesium-137 and Cesium-134 in fish meat from the North Sea purchased in Esbjerg in August 1979*

Species	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$	Bq ^{134}Cs kg^{-1}
Cod	0.039 B	11 B	6.4	1480	0.38
Plaice	0.020	32	2.8	710	0.170

Table 5.8.2.2.A. Strontium-90, Cesium-137 and Cesium-134 in fish meat from inner Danish waters purchased in Hundested in July 1979

Species	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{134}Cs kg^{-1}
Cod	4.4	3.3	115	30	4.2
Plaice	1.22	1.09	77	19.4	3.1 A
Herring	0.52	1.09	81	18.1	B.D.L.

Table 5.8.2.2.B. Strontium-90, Cesium-137 and Cesium-134 in fish meat from inner Danish waters purchased in Hundested in July 1979

Species	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$	Bq ^{134}Cs kg^{-1}
Cod	0.163	122	4.3	1110	0.155
Plaice	0.045	40	2.8	720	0.115
Herring	0.019	40	3.0	670	B.D.L.

It is estimated from the prediction models for ^{137}Cs in fish[21] that fallout contributed 20-30% of the ^{137}Cs level observed. The remaining part ~ 80 pCi ^{137}Cs kg^{-1} was attributed to releases from Windscale.

A similar result was obtained if we used the $^{134}Cs/^{137}Cs$ ratio for the estimate. The expected ratio in pure Windscale radiocesium was 0.06 (cf. 4.4) and we found 0.05, i.e. 83%.

In February 1980 "Denmark's Fishery and Sea Investigations" collected a number of herring samples from the North Sea.

The samples represented two age groups of herrings: One from autumn 1977 (one winterring) and the other from autumn 1976 (two winterrings). The herrings were caught at three locations close to 54°N lattitude (cf. Table 5.8.2.3). For the samples closest to England the young herrings contained nearly two times as much ^{137}Cs as the other samples, which were not significantly different. The $^{134}Cs/^{137}Cs$ mean ratio in the samples was 0.080± 0.009 (1 SD), which is higher than that observed in Tables 4.8.2.1 and 4.8.2.2. An isotopic ratio of 0.08 suggests an age

Table 5.8.2.3.A. Strontium-90, Cesium-137 and Cesium-134 in herring collected in the North Sea in February 1979

Age in years	Location		pCi ^{137}Cs kg^{-1}	M.U.	pCi ^{134}Cs kg^{-1}	pCi ^{90}Sr kg^{-1}	S.U.
1.5	54°11'N	5°03'5E	250	58	19.5		
2.5	- " -	- " -	184	40	16.9		
1.5	53°56'N	1°12' E	540	114	42	2.4 A	0.4 A
2.5	- " -	- " -	290	64	25		
1.5	54°25'N	4°45' E	230	50	15 A		
2.5	- " -	- " -	240	53	18.1		

Table 5.8.2.3.B. Strontium-90, Cesium-137 and Cesium-134 in herring collected in the North Sea in February 1979

Age in years	Location		Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{134}Cs kg^{-1}	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$
1.5	54°11'N	5°03'5E	9.2	2100	0.72		
2.5	- " -	- " -	6.8	1480	0.63		
1.5	53°56'N	1°12' E	20	4200	1.55	0.09 A	15 A
2.5	- " -	- " -	10.7	2400	0.92		
1.5	54°25'N	4°45' E	8.5	1850	0.6 A		
2.5	- " -	- " -	8.9	1960	0.67		

of the Windscale radiocesium in the herrings of 2-3 years, if the cesium ratio in the fresh Windscale release is approx. 0.2.

As compared with the ^{137}Cs and ^{90}Sr concentrations in the herring samples from inner Danish waters (Table 5.8.2.2), the North Sea herring contained 3-4 times more ^{137}Cs; but an equal amount of ^{90}Sr of 0.4 (pCi ^{90}Sr (g Ca)$^{-1}$).

5.8.3. Strontium-90 and Cesium-137 in various foods

Eggs and chicken were collected in Copenhagen and Roskilde in 1979. As compared with the corresponding sampling in 1978, the levels were a little lower in 1979.

Table 5.8.3.A. Strontium-90 and Cesium-137 in eggs from Copenhagen and chickens from Roskilde in August 1979

	pCi ^{90}Sr kg^{-1}	S.U.	pCi ^{137}Cs kg^{-1}	M.U.
Eggs	1.1 A	1.2 A	1.4 A	1.0 A
Chicken meat	0.11 B	1.0 B	7.2	2.6
Chicken bone		1.54		

Table 5.8.3.B. Strontium-90 and Cesium-137 in eggs from Copenhagen and chickens from Roskilde in August 1979

	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
Eggs	0.042 A	46 A	0.051 A	30 A
Chicken meat	0.004 B	38 B	0.27	96
Chicken bone		57		

5.9. Estimate of the mean contents of ^{90}Sr and ^{137}Cs in the human diet in Denmark in 1979

5.9.1. The annual quantities

The annual quantities are calculated by multiplication of the daily quantities by 365 (as stated by E. Hoff-Jørgensen, cf. Risø Report No. 63, Table B[1]).

Table 5.9.1. Estimate of the ^{90}Sr content in grain products consumed per capita in 1979

Type	Fraction from harvest 1978			Fraction from harvest 1979			Total
	kg flour	pCi kg^{-1}	pCi	kg flour	pCi kg^{-1}	pCi	pCi
Rye flour (100% extraction)	21.9	23	504	7.3	20	146	650
Wheat flour (75% extraction)	32.9	5.0	165	10.9	4.0	44	209
Grits	5.5	8.0	44	1.8	8.0	14	58
Total	60.3	11.8	713	20.0	10.2	204	917

5.9.2. Milk and cream

The ^{90}Sr and ^{137}Cs contents per kg milk were calculated from the annual mean values for dried milk (cf. Tables 5.1.1 and 5.1.3). 1 kg ~ 1 l milk, containing approx. 1.2 g Ca and 1.66 g K. Hence the mean contents in milk were 3.5 pCi ^{90}Sr kg^{-1} and 4.8 pCi ^{137}Cs kg^{-1}.

Table 5.9.2. Estimate of the ^{137}Cs content in grain products consumed per capita in 1979

Type	Fraction from harvest 1978			Fraction from harvest 1979			Total
	kg flour	pCi kg^{-1}	pCi	kg flour	pCi kg^{-1}	pCi	pCi
Rye flour (100% extraction)	21.9	40	876	7.3	12.2	89	965
Wheat flour (75% extraction)	32.9	10.0	329	10.9	3.9	43	372
Grits	5.5	10.4	57	1.8	4.3	8	65
Total	60.3	21.0	1262	20.0	7.0	140	1402

5.9.3. Cheese

One kg of cheese contains approx. 8.5 g Ca and 1.2 g K. The ^{90}Sr and ^{137}Cs contents in cheese were calculated from these figures and from the S.U. and M.U. levels in dried milk (cf. Tables 5.1.1 and 5.1.3). One kg of cheese appeared to contain 24.6 pCi ^{90}Sr and 3.5 pCi ^{137}Cs.

5.9.4. Grain products

Tables 5.8.1 and 5.9.2 show the estimates of ^{90}Sr and ^{137}Cs, respectively, in grain products consumed in 1979. From these tables, the activity levels in grain products were estimated at 11.4 pCi ^{90}Sr kg^{-1} and 17.5 pCi ^{137}Cs kg^{-1}.

5.9.5. Potatoes

The figures in Table 5.5.1 were used, i.e. 2.0 pCi ^{90}Sr kg^{-1} and 2.1 pCi ^{137}Cs kg^{-1}.

5.9.6. Vegetables

Table 5.6.3 shows the calculation of ^{90}Sr and ^{137}Cs in Danish vegetables consumed in 1979. The mean contents were 6.9 pCi ^{90}Sr kg^{-1} and 1.7 pCi ^{137}Cs kg^{-1}.

5.9.7. Fruit

The levels in imported fruit in 1979 are assumed to be equal to the mean levels found in oranges and bananas collected in Copenhagen in 1978, i.e. 3.9 pCi ^{90}Sr kg^{-1} and 1.3 pCi ^{137}Cs kg^{-1}. The mean levels in Danish fruit (apples) in 1979 were 0.5 pCi ^{90}Sr kg^{-1} and 1.9 pCi ^{137}Cs kg^{-1} (cf. 5.6). The daily mean consumption of fruit consisted of 100 g of Danish and 40 g of foreign origin. Hence the mean contents in fruit were 1.5 pCi ^{90}Sr kg^{-1} and 1.7 pCi ^{137}Cs kg^{-1}.

5.9.8. Meat

The annual mean values of ^{90}Sr and ^{137}Cs in meat were calculated from Table 5.8.1: 1.1 pCi ^{90}Sr kg^{-1} and 17.5 pCi ^{137}Cs kg^{-1}. (In a Danish diet meat comprises 2/3 pork and 1/3 beef).

5.9.9. Fish

The ^{90}Sr and ^{137}Cs contents in fish are estimated from 5.8.2 at 2 pCi ^{90}Sr kg^{-1} and 104 pCi ^{137}Cs kg^{-1}.

5.9.10. Eggs

The contents of activity in eggs were estimated from 5.8.3. The levels were 1.1 pCi ^{90}Sr kg^{-1} and 1.4 pCi ^{137}Cs kg^{-1}.

5.9.11. Coffee and tea

One third of the total consumption consists of tea and two thirds of coffee. The mean contents were in 1978 29 pCi ^{90}Sr kg^{-1} and 71 pCi ^{137}Cs kg^{-1} and these figures were used.

5.9.12. Drinking water

The ^{90}Sr level (population-weighted mean) found in drinking water collected in April 1979 was used as the mean level for drinking water, i.e. 0.02 pCi ^{90}Sr l^{-1}. The ^{137}Cs content in drinking water is assumed to be negligible.

5.9.13. Discussion

Tables 5.9.3 and 5.9.4 show the estimates of ^{90}Sr and ^{137}Cs in the Danish diet in 1979. The figures should be compared with the levels calculated from the total-diet samples (cf. 5.7). The ^{90}Sr estimates obtained by the two methods (cf. also fig. 5.7.1) were 4.0 S.U. and 4.3 S.U., respectively, and the ^{137}Cs estimates were 13.9 pCi ^{137}Cs (day)$^{-1}$ and 13.0 pCi ^{137}Cs (day)$^{-1}$

Table 5.9.3. Estimate of the mean content of ^{90}Sr in the human diet in Denmark in 1979

Type of food	Annual quantity in kg	pCi ^{90}Sr per kg	Total pCi ^{90}Sr	Percentage of total pCi ^{90}Sr in food
Milk and cream	164.0	3.5	574	22.3
Cheese	9.1	24.6	224	8.7
Grain products	80.3	11.4	917	35.6
Potatoes	73.0	2.0	146	5.7
Vegetables	43.8	6.9	302	11.7
Fruit	51.1	1.5	77	3.0
Meat	54.7	2.4	131	5.1
Eggs	10.9	1.1	12	0.5
Fish	10.9	2	22	0.8
Coffee and tea	5.5	29	160	6.2
Drinking water	548	0.02	11	0.4
Total			2576	

The mean calcium intake was estimated at 620 g (approx. 200-250 g Creta praeparata). Hence the ^{90}Sr/Ca ratio in the total diet was 4.2 S.U. in 1979.

<u>Table 5.9.4</u>. Estimate of the mean content of ^{137}Cs in the human diet in Denmark in 1979

Type of food	Annual quantity in kg	pCi ^{137}Cs per kg	Total pCi ^{137}Cs	Percentage of total pCi ^{137}Cs in food
Milk and cream	164.0	4.8	787	15.5
Cheese	9.1	3.5	32	0.6
Grain products	80.3	17.5	1402	27.6
Potatoes	73.0	2.1	153	3.0
Vegetables	43.8	1.7	74	1.5
Fruit	51.1	1.7	126	2.5
Meat	54.7	17.5	957	18.9
Eggs	10.9	1.4	15	0.3
Fish	10.9	104	1134	22.4
Coffee and tea	5.5	71	390	7.7
Drinking water	548	0	0	0
Total			5070	

As the approximate intake of potassium was 1365 g, the pCi ^{137}Cs (g K)$^{-1}$ ratio was approx. 3.7. The daily mean intake in 1979 was 13.9 pCi ^{137}Cs per caput.
If we neglect the contribution of ^{137}Cs to fish from Windscale (~ 80%) (5.8.2) the daily ^{137}Cs intake with total diet in 1979 would decrease with approx. 20 per cent to 11.4 pCi ^{137}Cs per caput.

The ratio between observed and predicted (cf. Appendix C) diet levels was 0.91 for ^{90}Sr and 0.66 for ^{137}Cs (corrected for Windscale ^{137}Cs).

The relative contributions of ^{90}Sr from milk products (~ 32%) and from grain (37%) were similar to those in 1978. The contribution from potatoes, other vegetables, and fruit was ~ 21%, i.e. also nearly unchanged from 1978. The relative contribution of ^{137}Cs in the total diet changed from 1978 to 1979 as follows: milk products (19 to 16%), grain products increased from 21 to 28%, and meat decreased (30 to 19%). Fish contributed 22% to the total ^{137}Cs intake in 1979, and is now the second important source of ^{137}Cs. This is, however, due to the ^{137}Cs contribution from Windscale. If this was excluded, milk products would contribute with 20%, grain: 34%, meat: 23% and fish: 5%.

5.10. Grass collected around Risø

Table 5.10 shows the ^{90}Sr content in grass ash from Zealand in 1979. The mean ^{90}Sr activity was 1.5 pCi ^{90}Sr (g ash)$^{-1}$, or 26 S.U., as compared with 2.5 pCi (g ash)$^{-1}$, or 53 S.U., in 1978, i.e. the 1979 level was approx. 60% of the 1978 level. Figure 5.10 shows the ^{90}Sr concentration in grass since 1957. The ratio between observed and predicted (cf. Appendix C.1) ^{90}Sr level in grass in 1979 was 1.28.

Table 5.10.A. Strontium-90 in grass from Zealand, 1979

	pCi ^{90}Sr (g ash)$^{-1}$	pCi ^{90}Sr (g Ca)$^{-1}$
Jan-March	1.31	32
April-June	1.17±0.05	24±1
July-Sept	1.89±0.04	27±0
Oct-Dec	1.58±0.03	23±0
Mean	1.49	26

The error term is 1 S.E. of the mean of double determinations.

Table 5.10.B. Strontium-90 in grass from Zealand, 1979

	Bq ^{90}Sr (kg ash)$^{-1}$	Bq ^{90}Sr (kg Ca)$^{-1}$
Jan-March	48	1180
April-June	43	890
July-Sept	70	1000
Oct-Dec	58	850
Mean	55	960

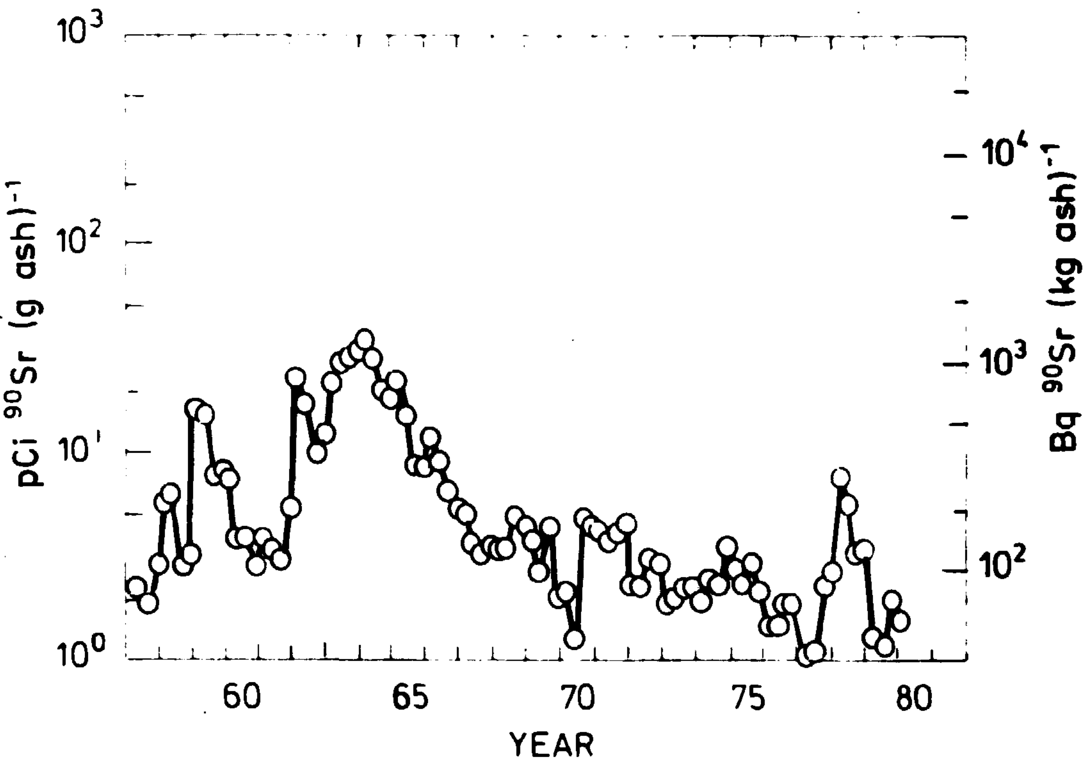


Fig. 5.10. Quarterly ^{90}Sr levels in grass, 1957-1979.

5.11. Sea plants

5.11.1. Sea plants collected in Roskilde Fjord

Figure 5.11.1 shows the S.U. levels in sea plants since 1959 and Table 5.11 the results for 1979. The level in Fucus vesiculosus was 11.8 pCi ^{90}Sr (g Ca)$^{-1}$, and in Zostera marina 2.0 pCi ^{90}Sr (g Ca)$^{-1}$. The mean ratio between observed and predicted ^{90}Sr levels in sea plants was 0.83.

Table 5.11.1.A. Strontium-90 and Cesium-137 in sea plants from Roskilde Fjord in 1979

Location	Species	pCi ^{90}Sr (g Ca)$^{-1}$	pCi ^{90}Sr (g ash)$^{-1}$	pCi ^{137}Cs (g K)$^{-1}$	pCi ^{137}Cs (g ash)$^{-1}$
I	Fucus vesiculosus	11.8	0.92	6.6	10.6
IX	Zostera marina	2.0	0.162	B.D.L.	B.D.L.

Table 5.11.2.A. Gamma-emitting radionuclides in Fucus vesiculosus and Fucus serratus in inner Danish waters collected in April-May 1979

Location	Species	Salinity o/oo	pCi ^{137}Cs kg^{-1} fresh weight	M.U.	pCi ^{60}Co kg^{-1} fresh weight	pCi ^{54}Mn kg^{-1} fresh weight
Fornæs fyr	Fucus serratus		32	12.3		
" "	Fucus vesiculosus		42	11.2		
Hesselø	Fucus serratus		68±9	11.5±0.9	13.6±3.2	
Dokkedal strand	Fucus vesiculosus	21.7	48	7.6		
Svenskehavn	Fucus vesiculosus		43	9.0		
Østerbyhavn stenmole (Læsø)	Fucus serratus	25.8	29	11.1		
Grenå mole	Fucus vesiculosus	22.3	32	10.0		
Udbyhøj strand	Fucus vesiculosus	27.3	50	11.9		
Rugård strand	Fucus vesiculosus	26.8	72	12.9		
Sæby bugt	Fucus vesiculosus	11.7	46	9.8		11.4 A
Grenå stenmole	Fucus serratus		56	9.3		
Sæby stenmole	Fucus serratus	32.2	89	14.1		
" "	Fucus vesiculosus	32.2	104	18.0		
Læsø vest	Fucus serratus	23.3	54	10.8		7.7 B
" "	Fucus vesiculosus	23.3	32	9.4		10.8
Torekov	Fucus serratus		53	10.7	41	
Anholt havn	Fucus vesiculosus		49	9.9	5.3 A	3.5 A
Anholt Vesterstrand	Fucus serratus		30	7.4		
Skovshoved havn, læmole	Fucus serratus		58	10.6	79	9.0 A
Gilleleje	Fucus vesiculosus		35	10.7	4.5	
Helsingør	Fucus serratus		40	9.5	31	
Mikkelborg	Fucus vesiculosus		59	11.0	15.9	
Mean	Fucus vesiculosus		51	10.9		
S.D.	" "		20	2.6		
S.E.	" "		6	0.8		
Mean	Fucus serratus		51	10.7		
S.D.	" "		19	1.8		
S.E.	" "		6	0.6		

Table 5.11.2.B. Gamma-emitting radionuclides in Fucus vesiculosus and Fucus serratus in inner Danish waters collected in April-May 1979

Location	Species	Salinity o/oo	Bq ^{137}Cs kg^{-1} fresh weight	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{60}Co kg^{-1} fresh weight	Bq ^{54}Mn kg^{-1} fresh weight
Fornæs fyr	Fucus serratus		1.18	460		
" "	Fucus vesiculosus		1.55	410		
Hesselø	Fucus serratus		2.5	430	0.50	
Dokkedal strand	Fucus vesiculosus	21.7	1.78	280		
Svenskehavn	Fucus vesiculosus		1.59	330		
Østerbyhavn stenmole (Læsø)	Fucus serratus	25.8	1.07	410		
Grenå mole	Fucus vesiculosus	22.3	1.18	370		
Udbyhøj strand	Fucus vesiculosus	27.3	1.85	440		
Rugård strand	Fucus vesiculosus	26.8	2.7	480		
Sæby bugt	Fucus vesiculosus	11.7	1.70	360		0.42 A
Grenå stenmole	Fucus serratus		2.1	340		
Sæby stenmole	Fucus serratus	32.2	3.3	520		
" "	Fucus vesiculosus	32.2	3.8	670		
Læsø vest	Fucus serratus	23.3	2.0	400		0.28 B
" "	Fucus vesiculosus	23.3	1.18	350		0.40
Torekov	Fucus serratus		1.96	400	0.152	
Anholt havn	Fucus vesiculosus		1.81	370	0.196 A	0.130 A
Anholt Vesterstrand	Fucus serratus		1.11	270		
Skovshoved havn, læmole	Fucus serratus		2.1	390	2.9	0.33 A
Gilleleje	Fucus vesiculosus		1.30	400	0.166	
Helsinger	Fucus serratus		1.48	350	1.15	
Mikkelborg	Fucus vesiculosus		2.2	410	0.59	
Mean	Fucus vesiculosus		1.89	400		
S.D.	" "		0.74	96		
S.E.	" "		0.22	30		
Mean	Fucus serratus		1.89	400		
S.D.	" "		0.70	67		
S.E.	" "		0.22	22		

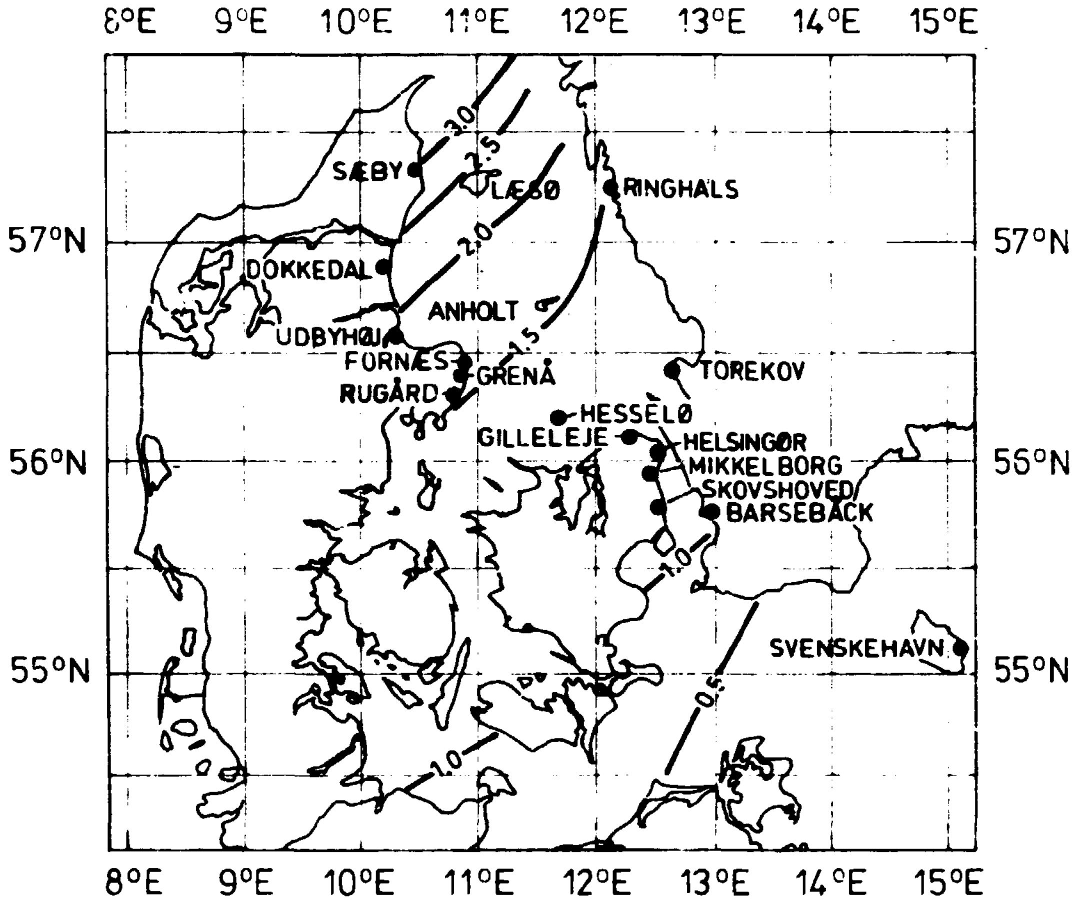


Fig. 5.11.2. Locations used in the Fucus sampling in May-June 1979 (cf. 5.11.2 and 8.2). The ^{137}Cs isoconcentration curves (in pCi l^{-1}) were estimated from the sea water analysis performed in May-June 1979 and from salinities in surface waters (cf. the regression equation for ^{137}Cs in 4.4).

Figure 5.11.2 shows that there was no evident correlation between ^{137}Cs concentrations in sea water and fucoids. However, this may be due to higher concentration factors (from sea water to fucoids) for low salinities than for high. For salinities less than 20 o/oo the mean ratio between pCi ^{137}Cs kg^{-1} fresh weight of fucoids and pCi ^{137}Cs l^{-1} sea water was approx. 40, while it was approx. 25 for salinities higher than 20 o/oo. Hence, although the ^{137}Cs concentration was approx. two times higher in the water with the higher salinities, this did not enhance the fucoid concentrations relative to those in the lower salinity water.

Cobalt-60 and ^{54}Mn were measurable in some samples, especially those relatively close to Barsebäck and Ringhals.

5.12. Animal fodder

A few samples of fodder collected in 1979 were analysed for ^{137}Cs. Table 5.12 shows that the imported fodder contained less ^{137}Cs than Danish fodder. Soya meal contained approx. one third of the ^{137}Cs concentration found in Danish fodder from 1979 while linseed and cottonseed contained less than 10% of the Danish fodder level.

Table 5.12.A. Cesium-137 in fodder collected in March 1979

Species	pCi ^{137}Cs kg^{-1}	pCi ^{137}Cs $(g\ K)^{-1}$
Soya meal	52	2.0
Linseed	14.5 A	2.0 A
Mixed, purely Danish fodder	142	7.3
Cotton seed cakes	10.7 B	0.7 B
Linseed cakes	6.1 B	0.6 B

Table 5.12.B. Cesium-137 in fodder collected in March 1979

Species	*Bq ^{137}Cs kg^{-1}*	*Bq ^{137}Cs $(kg\ K)^{-1}$*
Soya meal	*1.9*	*74*
Linseed	*0.54 A*	*74 A*
Mixed, purely Danish fodder	*5.3*	*270*
Cotton seed cakes	*0.40 B*	*26 B*
Linseed cakes	*0.23 B*	*22 B*

6. STRONTIUM-90 AND CESIUM-137 IN MAN IN 1979

by A. Aarkrog and J. Lippert

6.1. Strontium-90 in human bone

The collection of human vertebrae from the institutes of forensic medicine in Copenhagen and Århus was continued in 1979. As in the total-diet survey (cf. 5.7), the country was divided into eight zones. The samples were divided into five age groups: new-born (< 1 month), infants (1 month-4 years), children and teenagers (5-19 years), adults (≤ 29 years), and adults (> 29 years), however, no samples of new-borns bone were obtained in 1979.

Tables 6.1.2-6.1.5 show the results for the four groups.

Table 6.1.1. Strontium-90 in bone from new-born children (< 1 month old) in 1979

No samples.

Table 6.1.2 . Strontium-90 in bone from infants (≤ 4 years) in 1979

Zone	Age in years and months	Month of death	Sex	pCi ^{90}Sr (g Ca)$^{-1}$
II	3 m	4	M	0.79
III	11 m	4	M	1.0 B
VI	2 y 1 m	4	F	0.4 B

Table 6.1.2.B. Strontium-90 in bone from infants (≤ 4 years) in 1979

Zone	Age in years and months	Month of death	Sex	Bq ^{90}Sr (kg Ca)$^{-1}$
II	3 m	4	M	29
III	11 m	4	M	39 B
VI	2 y 1 m	4	F	14 B

Table 6.1.3.A. Strontium-90 in bone from children and teenagers (≤ 19 years) in 1979

Zone	Age in years	Month of death	Sex	pCi ^{90}Sr (g Ca)$^{-1}$
I	12	4	F	0.87
II	5	4	F	0.66
II	18	4	F	0.60
V	9	7	M	0.54
VI	16	9	F	0.76
VI	18	10	F	1.11
VI	19	4	F	0.79
VI	6	3	M	0.86
VI	6	10	M	0.82
VI	11	4	M	0.50
VI	13	4	M	0.4 B
VI	14	4	M	0.59
VI	14	4	M	0.61
VI	15	10	M	0.85
VI	16	10	M	0.66
VI	18	7	M	0.4 B

Table 6.1.3.B. Strontium-90 in bone from children and teenagers (≤ 19 years) in 1979

Zone	Age in years	Month of death	Sex	Bq ^{90}Sr (kg Ca)$^{-1}$
I	12	4	F	32
II	5	4	F	24
II	18	4	F	22
V	9	7	M	20
VI	16	9	F	28
VI	18	10	F	41
VI	19	4	F	29
VI	6	3	M	32
VI	6	10	M	30
VI	11	4	M	18.5
VI	13	4	M	15 B
VI	14	4	M	22
VI	14	4	M	23
VI	15	10	M	31
VI	16	10	M	24
VI	18	7	M	16 B

Table 6.1.4.A. Strontium-90 in vertebrae from adult ($\leq$ 29 years) in 1979

Zone	Age in years	Month of death	Sex	pCi ^{90}Sr (g Ca)$^{-1}$
II	26	4	F	1.35
VI	20	10	F	0.86
VI	22	4	F	0.66
VI	23	10	F	0.95
VI	25	7	F	0.6 A
VI	20	10	M	0.85
VI	28	3	M	1.13

Table 6.1.4.B. Strontium-90 in vertebrae from adults ($\leq$ 29 years) in 1979

Zone	*Age in years*	*Month of death*	*Sex*	*Bq ^{90}Sr (kg Ca)$^{-1}$*
II	26	4	F	50
VI	20	10	F	32
VI	22	4	F	24
VI	23	10	F	35
VI	25	7	F	21 A
VI	20	10	M	31
VI	28	3	M	42

The adult levels were similar to those in 1978, but children showed lower levels than last year. The observed mean concentration in adults ($\geq$ 30 years) was 84% of that predicted (cf. Appendix C).

Table 6.1.5.A. Strontium-90 in vertebrae from adults (> 29 years) in 1979

Zone	Age in years	Month of death	Sex	pCi ^{90}Sr (g Ca)$^{-1}$
I	37	3	M	1.07
I	65	3	M	0.95
I	76	4	M	0.62
II	32	3	F	1.05
II	47	4	F	1.04
II	47	3	F	0.90
II	32	4	M	1.08
IV	58	3	M	0.96
VI	30	4	F	0.78
VI	32	3	F	1.72
VI	36	8	F	2.6 A
VI	37	3	F	0.64
VI	30	3	M	0.56
VI	35	4	M	0.65
VI	42	3	M	0.63
Swedish*	24	7	F	1.4 B
Swedish*	27	7	M	1.54

*Not included in mean.

Table 6.1.5.B. Strontium-90 in vertebrae from adults (> 29 years) in 1979

Zone	Age in years	Month of death	Sex	Bq ^{90}Sr (kg Ca)$^{-1}$
I	37	3	M	40
I	65	3	M	35
I	76	4	M	23
II	32	3	F	39
II	47	4	F	38
II	47	3	F	33
II	32	4	M	40
IV	58	3	M	36
VI	30	4	F	29
VI	32	3	F	64
VI	36	8	F	94 A
VI	37	3	F	24
VI	30	3	M	21
VI	35	4	M	24
VI	42	3	M	23
Swedish*	24	7	F	53 B
Swedish*	27	7	M	57

*Not included in mean.

Table 6.1.6.A. Strontium-90 (pCi (g Ca)$^{-1}$) in human vertebrae collected in Denmark 1979

Age group	Number of samples	Number of analysis	Min.	Max.	Median	Mean
Infants (≤ 4 years)	3	3	0.37	1.05	0.79	0.73
Children (≤ 19 years)	16	16	0.41	1.11	0.66	0.69
Adults (≤ 29 years)	7	7	0.57	1.35	0.86	0.91
Adults (≥ 30 years)	15	15	0.56	2.55	0.95	1.01

Table 6.1.6.B. Strontium-90 (pCi (kg Ca)$^{-1}$) in human vertebrae collected in Denmark 1979

Age group	Number of samples	Number of analysis	Min.	Max.	Median	Mean
Infants (≤ 4 years)	3	3	13.7	39	29	27
Children (≤ 19 years)	16	16	15.2	41	24	26
Adults (≤ 29 years)	7	7	21	50	32	34
Adults (≥ 30 years)	15	15	21	94	35	37

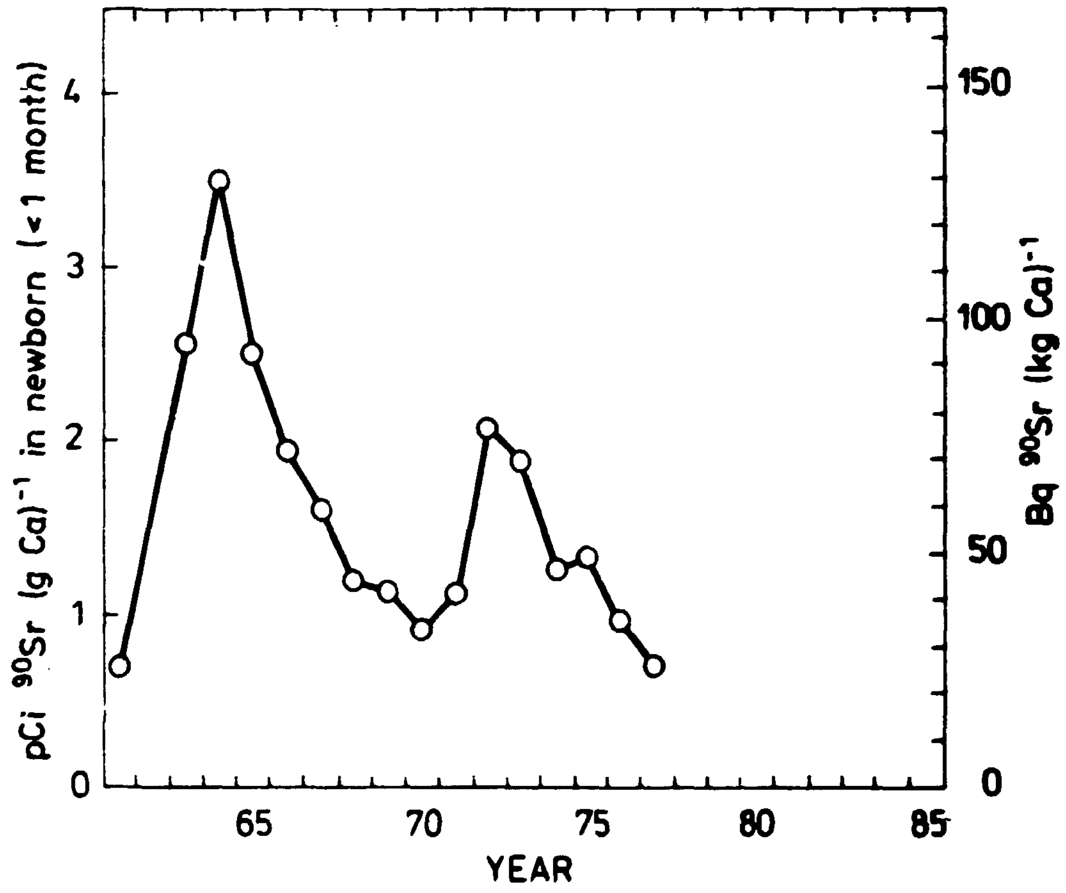


Fig. 6.1.1. Strontium-90 in bone from newborn 1961-1979.

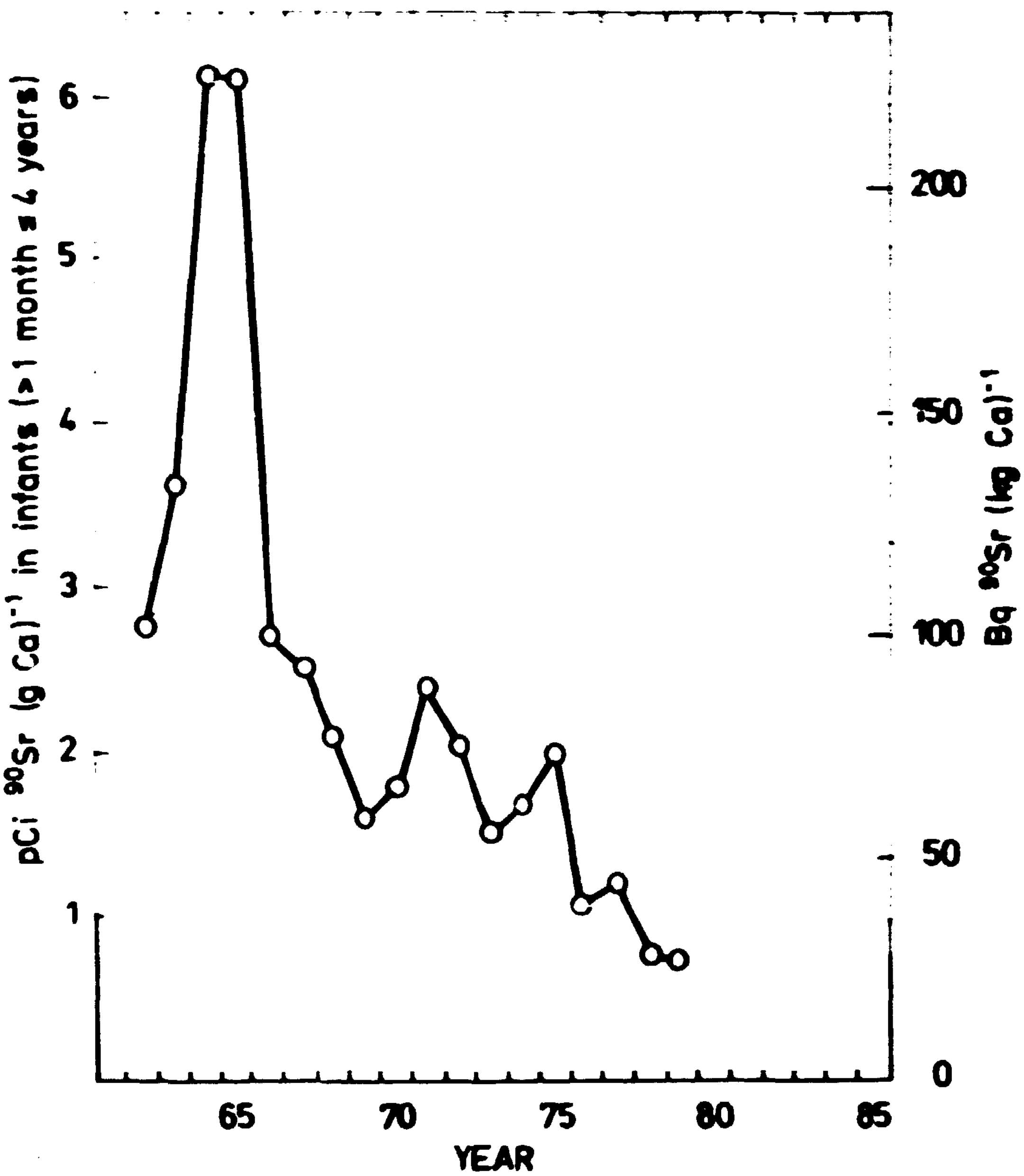


Fig. 4.1.2. Strontium-90 in bone from infants 1962-1979.

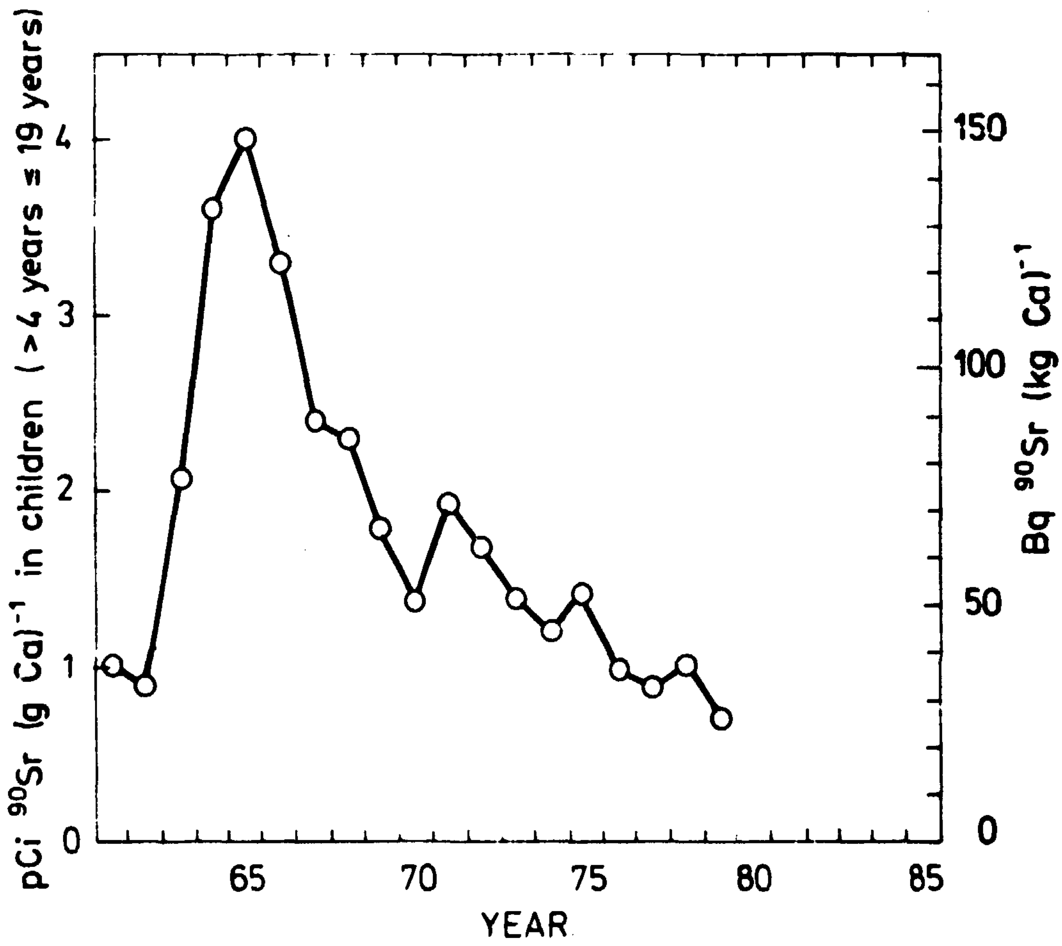


Fig. 6.1.3. Strontium-90 in bone from children 1961-1979.

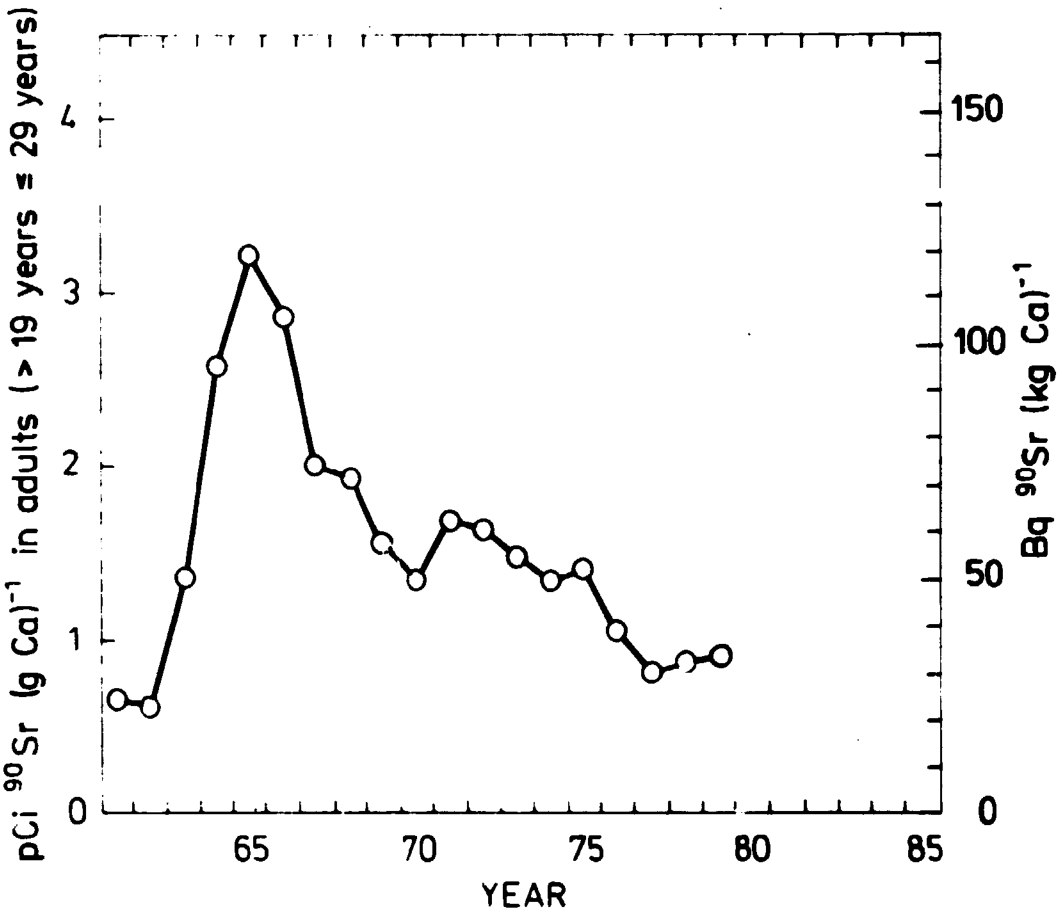


Fig. 6.1.4. Strontium-90 in vertebrae from adults ≤ 29 y, 1961-1979.

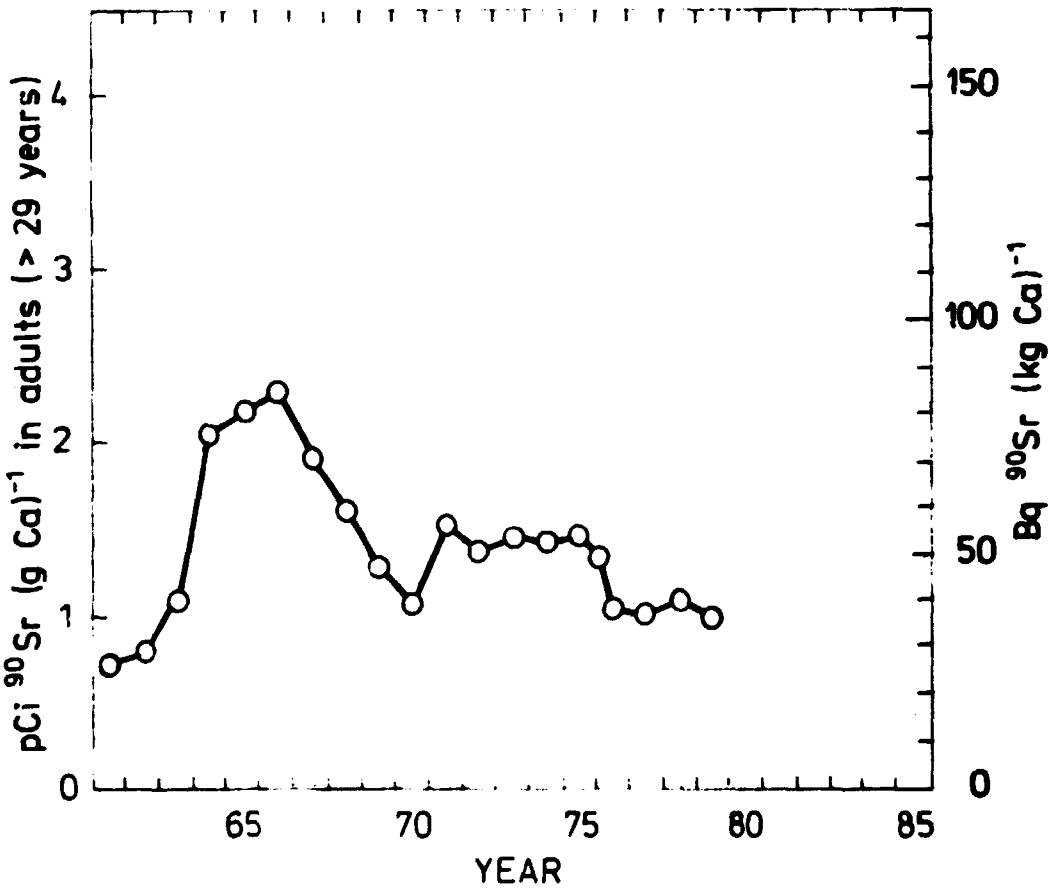


Fig. 6.1.5. Strontium-90 in vertebrae from adults > 29 y, 1961-1979.

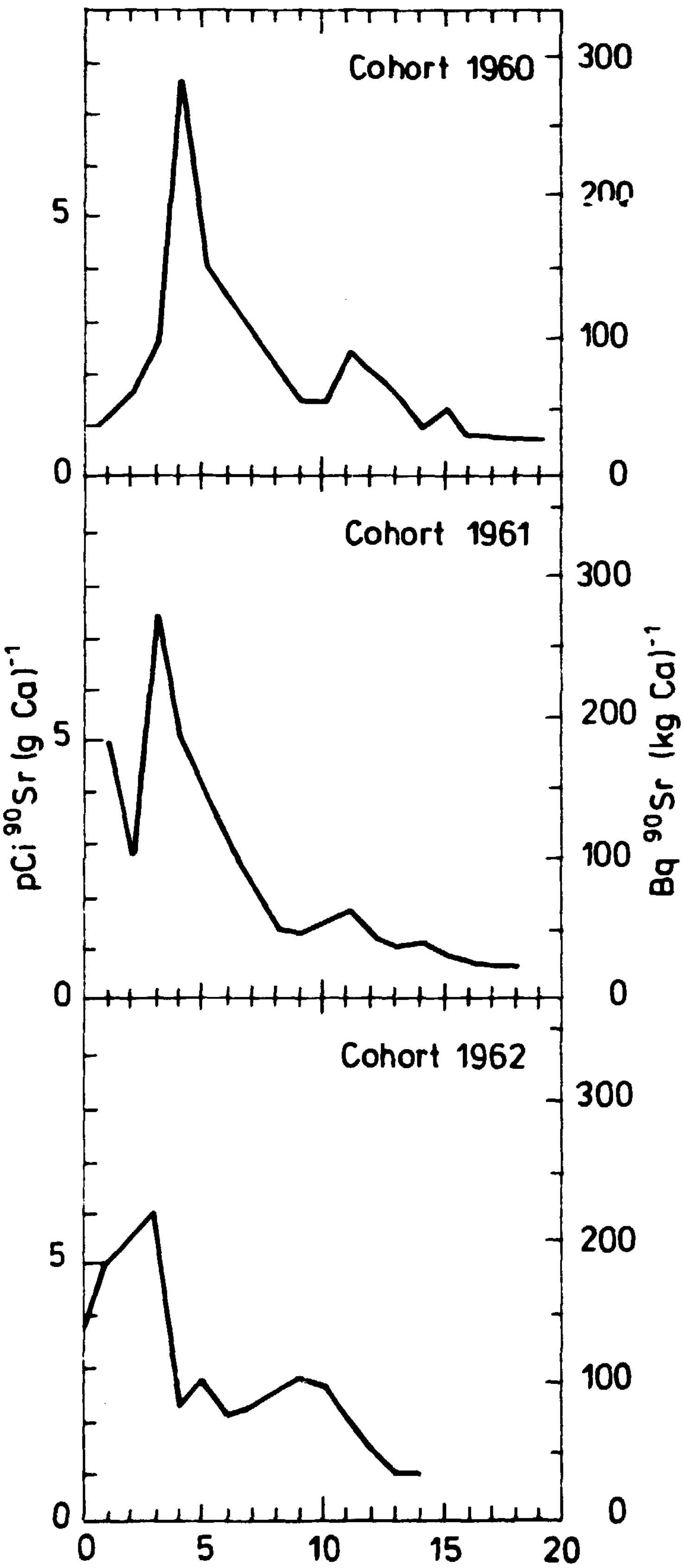
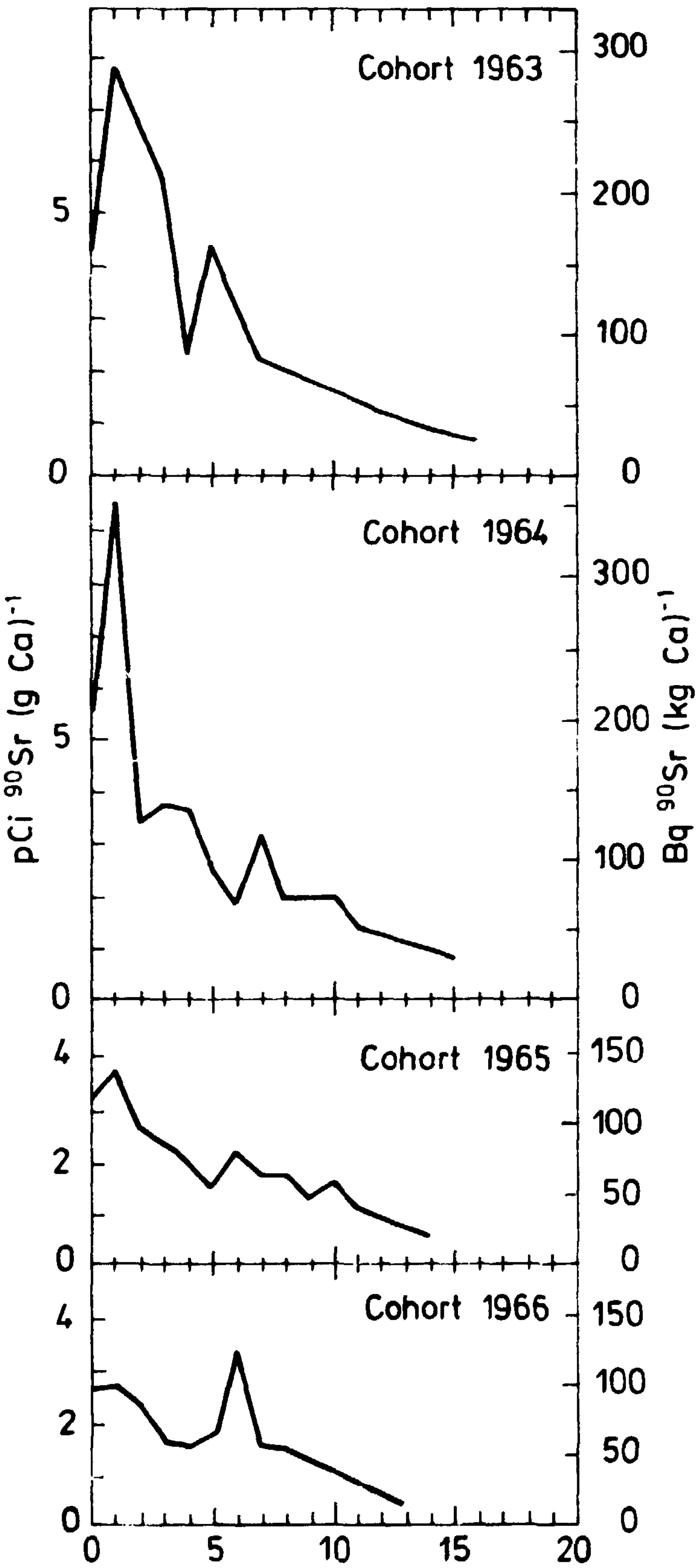


Fig. 6.1.6. Strontium-90 in human bone from Danish cohorts 1960-1966. Abscissa: age in years. Ordinate: bone level in pCi ^{90}Sr (g Ca)$^{-1}$.


Cohort 1963
Cohort 1964
Cohort 1965
Cohort 1966
pCi 90Sr (g Ca)-1
Bq 90Sr (kg Ca)-1
0
5
10
15
20
300
200
100
150
50
4
2

6.2. Cesium-137 in the human body

Whole-body measurements were initiated at Risø in July 1963 (cf. 2.3 in Risø Report No. 85[1]). A control group from the Health Physics Department was selected and has since then been measured as far as possible three times a year.

However, due to the decreasing ^{137}Cs content in the body the contribution from interfering radionuclides to the γ-spectra has made the determination of ^{137}Cs so unreliable that we have decided not to publish any whole-body results this year. The results from 1978[1] should also be deleted from our material because they are unreliable too.

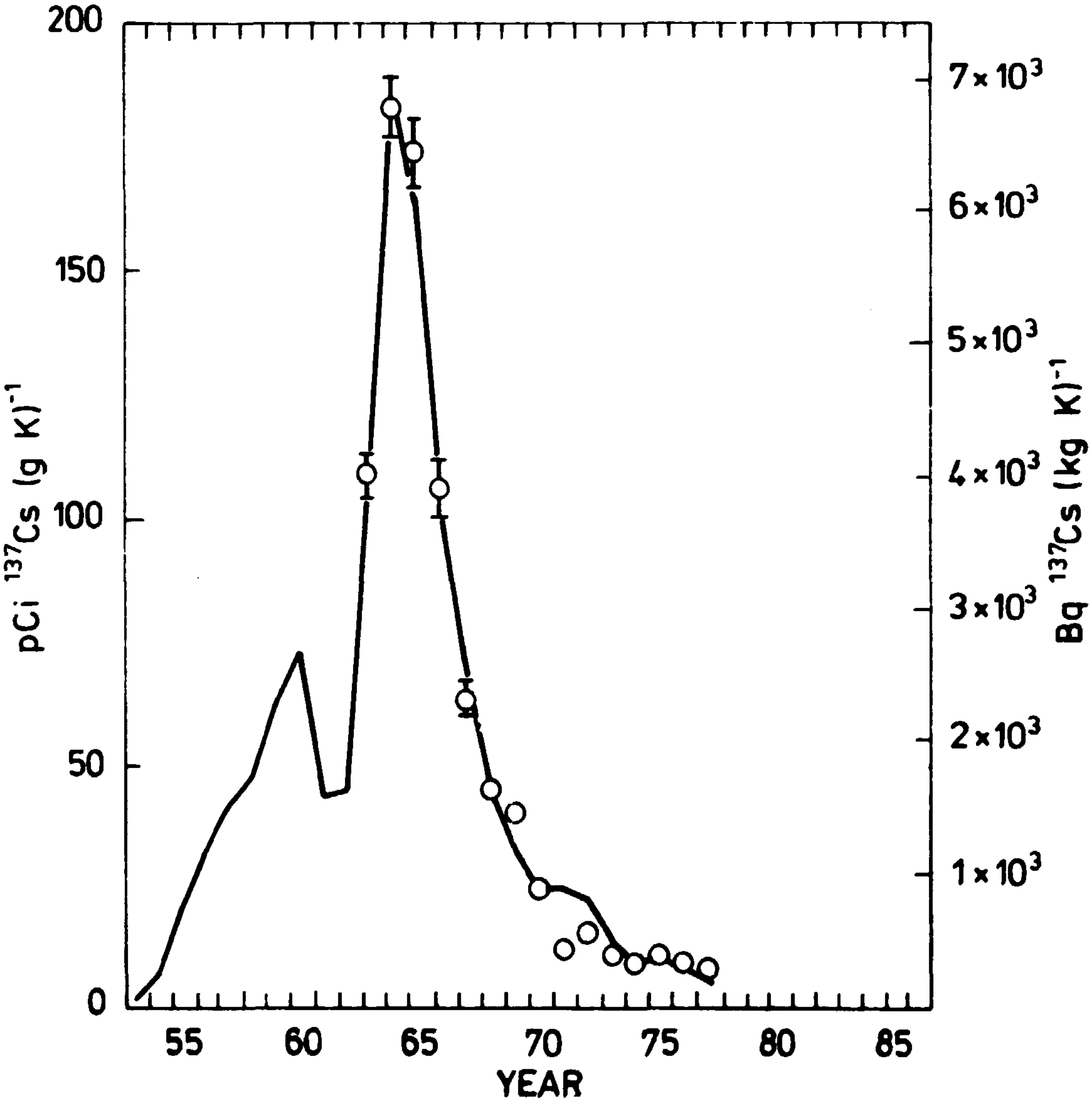


Fig. 6.2. A comparison between observed (± 1 SE) and calculated (curve, cf. Appendix C) pCi ^{137}Cs (g K)$^{-1}$ levels in whole-body from the Islands.

7. TRITIUM IN THE ENVIRONMENT

by Heinz Hansen

7.1. Introduction

Tritium is produced naturally in the atmosphere by the interaction of cosmic-ray protons and neutrons with nitrogen, oxygen or argon. Surface waters contain about 0.01 nCi l^{-1} from this source[25]. Tritium is also produced and injected into the stratosphere as the result of thermonuclear explosions. At present, this latter source has enhanced the natural inventory by about a factor of ten[25]. Finally, tritium is produced as a by-product of the peaceful uses of atomic energy: it is released both during reactor operation and fuel reprocessing.

Before Denmark builds any nuclear power stations of her own, it is of interest to know the general tritium levels in the environment that could be affected by this new energy source. Also, an assay of the current tritium levels can be used already now to control any tritium which may be released from the Swedish nuclear power stations at Barsebäck and Ringhals, and from the reprocessing plants at Windscale and La Hague.

7.2. Assay of tritium in low-level amounts

The present assays of tritium levels in water are based on a relative enrichment of ^3H_2O by electrolysis and subsequent liquid scintillation counting as previously described (Risø Reports Nos. 386, 403)[1]. This year we have introduced the following adaption:

Previously we distilled all samples prior to electrolysis using either glass beeds or pumice to avoid bumping. Now we distil over granulated active charcoal instead. We do this to avoid contamination of the samples by any volatile organic matter. This seems to have had a major effect on our results. Not only have we enhanced the reproducibility of our liquid scintillation counting, but we also seem to have removed some background contamination from sea-, lake-, and stream water samples. The mean ratios of pCi ^{3}H l^{-1}/pCi ^{90}Sr l^{-1} for the said samples shown in Table 7.3.6 are substantially lower for the present results than for those previously reported (Risø Report No. 403)[1].

7.3. Results

In 1979 the mean tritium concentrations in precipitation, stream water, lake water, and ground water were all nearly the same: 0.2 nCi l^{-1}. Drinking water was shown to contain 0.1 nCi ^{3}H l^{-1}; however, this mean value was not significantly different from that observed in ground water.

UNSCEAR[25] estimated the naturally occurring tritium concentration in continental surface waters as 6-24 pCi l^{-1}, i.e. in the order of 10% of the observed Danish levels in 1979. Hence, fallout tritium still is the important source of environmental tritium. The $^{3}H/^{90}Sr$ ratio in cumulative deposition is approx. 230[25]. As shown in Table 7.3.6 this ratio fits the observed

Table 7.3.1.A. Tritium in precipitation collected at Risø in 1979

Month	mm	nCi ^{3}H l^{-1}	mCi ^{3}H km^{-2}
Jan	15	0.19±0.01	2.8
Feb	10	0.16±0.00	1.6
March	41	0.38±0.02	15.6
April	28	0.18±0.00	5.0
May	46	0.18±0.04*	8.3
June	22	0.25±0.04	5.5
July	27	0.17±0.01	4.6
Aug	76	0.24±0.02	18.2
Sept	26	0.14±0.01*	3.6
Oct	22	0.14±0.00	3.1
Nov	65	0.16±0.00	10.4
Dec	73	0.26±0.04*	19.0
1979	Σ 451	0.22	Σ 98

The error term is 1 S.E. of the mean of double determinations.

*Triple determinations.

Table 7.3.1.B. Tritium in precipitation collected at Risø in 1979

Month	mm	Bq ^{3}H m^{-3}	Bq m^{-2}
Jan	15	7.0×10^{3}	104
Feb	10	5.9×10^{3}	59
March	41	14.1×10^{3}	580
April	28	6.7×10^{3}	185
May	46	6.7×10^{3}	310
June	22	9.2×10^{3}	200
July	27	6.3×10^{3}	170
Aug	76	8.9×10^{3}	670
Sept	26	5.2×10^{3}	133
Oct	22	5.2×10^{3}	115
Nov	65	5.9×10^{3}	380
Dec	73	9.6×10^{3}	700
1979	Σ 451	8.1×10^{3}	Σ 3.6×10^{3}

The error term is 1 S.E. of the mean of double determinations.

**Triple determinations.*

Table 7.3.2.A. Tritium in ground water collected in 1979 (cf. 4.3.1)

Location	Sampling month	nCi ^{3}H l^{-1}
Hvidsten	Feb	0.03±0.00
Feldbak	March	0.18±0.00
Rømø	March	0.07±0.02
Rønne new	June	0.06±0.02
Rønne old	June	0.15±0.04
Hasselø	Feb	0.25±0.01
Fåretofte	Feb	0.16±0.02
Kalungborg	Feb	0.22±0.02
Ravnholt	March	0.34±0.00
Fredericia	June	0.20±0.04
Mean		0.17±0.10 (1 SD)
Median		0.17

A sample of ground water from Maglekilde in Roskilde (collected in January) contained 0.35±0.01 nCi ^{3}H l^{-1}. The error term is 1 S.E. of the mean of double determinations.

Table 7.3.2.B. Tritium in ground water collected in 1979

Location	*Sampling month*	*Bq ^{3}H m^{-3}*
Hvidsten	*Feb*	*1.1×10^{3}*
Feldbak	*March*	*6.7×10^{3}*
Rømø	*March*	*2.6×10^{3}*
Rønne new	*June*	*2.2×10^{3}*
Rønne old	*June*	*5.6×10^{3}*
Hasselø	*Feb*	*9.2×10^{3}*
Fåretofte	*Feb*	*5.9×10^{3}*
Kalundborg	*Feb*	*8.1×10^{3}*
Ravnholt	*March*	*12.6×10^{3}*
Fredericia	*June*	*7.4×10^{3}*
Mean		*6.3×10^{3}*
Median		*6.3×10^{3}*

A sample of ground water from Maglekilde in Roskilde (collected in January) contained 13.0×10^{3} Bq ^{3}H m^{-3}.

Table 7.3.3.A. Tritium in drinking water from Denmark, collected in 1979 (cf. 4.3.3)

Zone		Month	nCi ^{3}H l^{-1}
I:	North Jutland	March	0.19±0.03
II:	East Jutland	April	0.08±0.02
III:	West Jutland	April	0.10±0.02
IV:	South Jutland	March	0.07±0.00
V:	Funen	April	0.08±0.00
VI:	Zealand	June	0.12±0.02
VII:	Lolland-Falster	April	0.05±0.01*
VIII:	Bornholm	June	0.16±0.03*
Mean			0.11±0.05 (1 S.D.)
Copenhagen		June	0.08±0.00
Population-weighted mean			0.10

The error term is 1 S.E. of the mean of double determinations.

*Triple determinations.

Table 7.3.3.B. Tritium in drinking water from Denmark, collected in 1979

Zone		*Month*	*Bq ^{3}H m^{-3}*
I:	*North Jutland*	*March*	*7.0×10^{3}*
II:	*East Jutland*	*April*	*3.0×10^{3}*
III:	*West Jutland*	*April*	*3.7×10^{3}*
IV:	*South Jutland*	*March*	*2.6×10^{3}*
V:	*Funen*	*April*	*3.0×10^{3}*
VI:	*Zealand*	*June*	*4.4×10^{3}*
VII:	*Lolland-Falster*	*April*	*1.85×10^{3}*
VIII:	*Bornholm*	*June*	*5.9×10^{3}*
Mean			*4.1×10^{3}*
Copenhagen		*June*	*3.0×10^{3}*
Population-weighted mean			*3.7×10^{3}*

Table 7.3.4.A. Tritium in Danish streams and lakes in February 1979. (Unit: nCi $^{3}H\ l^{-1}$ (±1 S.E.)) (cf. 4.3.2)

Zone		Streams		Lakes	
I:	North Jutland	Bangsbo å*	0.22±0.01	Norssø	0.16±0.02
II:	East Jutland	Guden å	0.09±0.02	Mossø	0.15±0.02
III:	West Jutland	Skjern å	0.14±0.01	Flyndersø	0.15±0.01
IV:	South Jutland	Ribe å	0.12±0.03	Hostrup sø	0.18±0.02
V:	Funen	Odense å*	0.18±0.04	Arreskov sø	0.12±0.04
VI:	Zealand	Suså	0.21±0.02	Arresø	0.18±0.01
VII:	Lolland-Falster	Halsted å	0.23±0.01	Søndersø	0.24±0.04
VIII:	Bornholm	Læså*	0.24±0.02	Almindingen sø*	0.28±0.04
Mean			0.18±0.06 (1 S.D.)		0.18±0.05 (1 S.D.)

*Collected in June.

Table 7.3.4.B. Tritium in Danish streams and lakes in February 1979. (Unit: Bq $^{3}H\ m^{-3}$)

Zone		Streams		Lakes	
I:	North Jutland	Bangsbo å*	8.1×10^{3}	Norssø	5.9×10^{3}
II:	East Jutland	Guden å	3.3×10^{3}	Mossø	5.6×10^{3}
III:	West Jutland	Skjern å	5.2×10^{3}	Flyndersø	5.6×10^{3}
IV:	South Jutland	Ribe å	4.4×10^{3}	Hostrup sø	6.7×10^{3}
V:	Funen	Odense å*	6.7×10^{3}	Arreskov sø	4.4×10^{3}
VI:	Zealand	Suså	7.8×10^{3}	Arresø	6.7×10^{3}
VII:	Lolland-Falster	Halsted å	8.5×10^{3}	Søndersø	8.9×10^{3}
VIII:	Bornholm	Læså*	8.9×10^{3}	Almindingen sø*	10.4×10^{3}
Mean			6.7×10^{3}		6.7×10^{3}

*Collected in June.

ratios for lake- and sea water. The observed ground- and drinking water ratios were, however, two orders of magnitude higher, which, as mentioned earlier[1], is explained by sorption of ^{90}Sr from water in contact with soil minerals.

Table 7.3.5.A. Tritium in sea water collected in 1979 (cf. 4.4)

Location	Position or station number N	E	Depth in m	Date	nCi $^3H\ l^{-1}$ ±1 S.E.	Salinity o/oo
Kullen	56°15'	12°25'	0	June	0.14±0.04	18.1
- " -	- " -	- " -	21	"	0.04±0.02	32.9
Kattegat W	56°07'	11°10'	0	June	0.20±0.02	15.3
- " -	- " -	- " -	40	"	0.08±0.00	34.3
Asnæs rev	55°38'	10°47'	0	June	0.21±0.02	15.3
- " -	- " -	- " -	43	"	0.07±0.01	32.8
Halskov rev	55°20'	11°02'	0	June	0.19±0.00	13.9
- " -	- " -	- " -	50	"	0.14±0.04	32.8
Langeland bælt	54°52'*	10°50'	0	June	0.22±0.02	16.6
- " -	- " -	- " -	50	"	0.08±0.00	30.7
Femern bælt	54°36'	11°05'	0	June	0.16±0.01	13.9
- " -	- " -	- " -	27	"	0.10±0.02	29.2
Gedser rev	54°28'	12°13'	0	June	0.23±0.06	10.4
- " -	- " -	- " -	25	"	0.12±0.00	24.3
Møn	54°57'	12°41'	0	June	0.20±0.04	10.3
- " -	- " -	- " -	20	"	0.22±0.02	11.8
The Sound-South	55°25'	12°39'	0	June	0.20±0.01	11.7
- " -	- " -	- " -	12	"	0.18±0.00	16.6
The Sound-North A	55°48'	12°44'	0	June	0.13±0.03	18.0
- " -	- " -	- " -	19	"	0.05±0.01	32.2
The Sound-North B	55°59'	12°42'	0	June	0.18±0.02	17.2
- " -	- " -	- " -	26	"	0.04±0.00	35.6
Kullen	56°15'	12°25'	0	Nov	0.16±0.04	25.7
The Sound-North B	55°59'	12°42'	0	"	0.13±0.02	25.0
Barsebäck	33		0	June	0.16±0.00	15.3
- " -	"		14	"	0.04±0.01	32.8
Barsebäck	34		0	June	0.15±0.01	18.2
- " -	"		16	"	0.05±0.00	32.9
Barsebäck	35		0	June	0.16±0.00	18.1
- " -	"		12	"	0.10±0.01	27.8
Ringhals	57°14'	11°53'7	0	May	0.15±0.02	21.3
- " -	- " -	- " -	70	"	0.06±0.02	35.6
Ringhals	1		0	May	0.12±0.00*	19.4
- " -	"		25	"	0.05±0.02	32.9
Ringhals	2		0	May	0.14±0.01	19.5
- " -	"		24	"	0.06±0.00	34.2
Ringhals	3		0	May	0.18±0.00	19.5
- " -	"		17	"	0.06±0.00	34.2
Ringhals	15		0	May	0.15±0.03	19.5
- " -	"		10	"	0.14±0.02	21.6

*Triple determinations.

Table 7.3.5.8. Tritium in sea water collected in 1979

Location	Position or station number N	E	Depth in m	Date	Bq ^{3}H m^{-3}	Salinity o/oo
Kullen	56°15'	12°25'	0	June	5.2×10^{3}	18.1
- " -	- " -	- " -	21	"	1.48×10^{3}	32.9
Kattegat W	56°07'	11°10'	0	June	7.4×10^{3}	15.3
- " -	- " -	- " -	40	"	3.0×10^{3}	34.3
Asnæs rev	55°38'	10°47'	0	June	7.8×10^{3}	15.3
- " -	- " -	- " -	43	"	2.6×10^{3}	32.8
Halskov rev	55°20'	11°02'	0	June	7.0×10^{3}	13.9
- " -	- " -	- " -	50	"	5.2×10^{3}	32.8
Langeland bælt	54°52'	10°50'	0	June	8.1×10^{3}	16.6
- " -	- " -	- " -	50	"	3.0×10^{3}	30.7
Femern bælt	54°36'	11°05'	0	June	5.9×10^{3}	13.9
- " -	- " -	- " -	27	"	3.7×10^{3}	29.2
Gedser rev	54°28'	12°13'	0	June	8.5×10^{3}	10.4
- " -	- " -	- " -	25	"	4.4×10^{3}	24.3
Møn	54°57'	12°41'	0	June	7.4×10^{3}	10.3
- " -	- " -	- " -	20	"	8.1×10^{3}	11.8
The Sound-South	55°25'	12°39'	0	June	7.4×10^{3}	11.7
- " -	- " -	- " -	12	"	6.7×10^{3}	16.6
The Sound-North A	55°48'	12°4[illegible]'	0	June	4.8×10^{3}	18.0
- " -	- " -	- " -	19	"	1.85×10^{3}	32.2
The Sound-North B	55°59'	12°42'	0	June	6.7×10^{3}	17.2
- " -	- " -	- " -	26	"	1.48×10^{3}	35.6
Kullen	56°15'	12°25'	0	Nov	5.9×10^{3}	25.7
The Sound-North B	55°59'	12°42'	0	"	4.8×10^{3}	25.0
Barsebäck	33		0	June	5.9×10^{3}	15.3
- " -	"		14	"	1.48×10^{3}	32.8
Barsebäck	34		0	June	5.6×10^{3}	18.2
- " -	"		16	"	1.85×10^{3}	32.9
Barsebäck	35		0	June	5.9×10^{3}	18.1
- " -	"		12	"	3.7×10^{3}	27.8
Ringhals	57°14'	11°53'7	0	May	5.6×10^{3}	21.3
- " -	- " -	- " -	70	"	2.2×10^{3}	35.6
Ringhals	1		0	May	4.4×10^{3}	19.4
- " -	"		25	"	1.85×10^{3}	32.9
Ringhals	2		0	May	5.2×10^{3}	19.5
- " -	"		24	"	2.2×10^{3}	34.2
Ringhals	3		0	May	6.7×10^{3}	19.5
- " -	"		17	"	2.2×10^{3}	34.2
Ringhals	15		0	May	5.6×10^{3}	19.5
- " -	"		10	"	5.2×10^{3}	21.6

Table 7.3.6. The mean ratio of pCi ^{3}H l^{-1}/pCi ^{90}Sr l^{-1} (±1 S.E.) in samples collected from various Danish waters in 1979

		Number of samples	Reference
Lake water	240 ± 190	8	Table 7.3.4.A and Table 4.3.2.A
Stream water	590 ± 140	8	- " - - " -
Ground water	33500 ± 26000	10	Table 7.3.2.A and Table 4.3.1.A
Drinking water	18700 ± 23000	9	Table 7.3.3.A and Table 4.3.3.A
Sea water	240 ± 80	11	Table 7.3.5.A and Table 4.4.1.A

Figure 7.1 shows that the tritium content in sea water varied with salinity. The regression was highly significant. For zero salinity the regression line predicts a tritium concentration of 0.28 nCi l^{-1}, which is not incompatible with the mean levels observed in streams and precipitation in the later years[1]. It is furthermore evident from Fig. 7.1 that tritium from Windscale and Swedish nuclear plants does not influence the tritium levels in Danish waters to any significant extent.

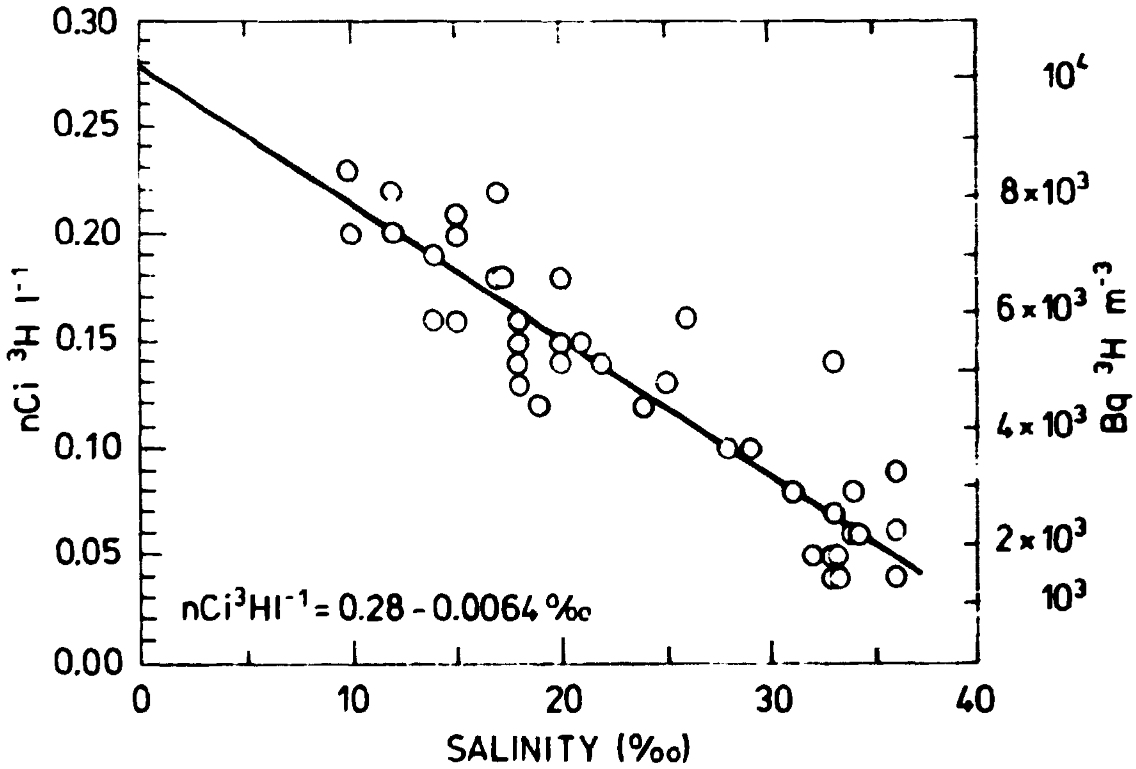


Fig. 7.1. Tritium in Danish Sea water related to salinity.

8. TRANSURANICS IN ENVIRONMENTAL SAMPLES

by Karen Nilsson

8.1. Sediment samples from the Sound

In May 1979 sediment samples were collected at position 38 at Barsebäck (Fig. 3.2.1.1); these were five Nordic sediment samplers (cf. Table 3.2.4.1). These samples were also analysed for $^{239,240}Pu$ and ^{241}Am. Table 8.1 shows the results of the analy-

Table 8.1.A. Plutonium in sediment samples collected at Barsebäck (location 38) May 7, 1979

Sample collector	Depth in cm	pCi $^{239,240}Pu$ kg^{-1}	Am/Pu	mCi $^{239,240}Pu$ km^{-2}
P1	0-2	68	0.23	0.56
"	2-4	52	0.26	0.50
"	4-10			
P1	0-10			Σ 1.06
P2	0-2	59	0.35	0.59
"	2-4	47		0.52
"	4-10	3		0.11
P2	0-10			Σ 1.22
P3	0-2	46	0.32	0.33
"	2-4	61	0.36	0.55
"	4-10	6	0.30	0.19
P3	0-10			Σ 1.07
P4	0-2	63	0.23	0.60
"	2-4	40		0.46
"	4-6	13	0.25	0.16
P4	0-6			Σ 1.22
P5	0-2	64	0.21	0.61
"	2-4	65	0.26	0.78
"	4-10	12	0.24	0.42
P5	0-10			Σ 1.81

ses performed at Risø. The samples were furthermore analysed at four other Nordic laboratories. This intercomparison project was supported by the Nordic Council of Ministers (NKA).

The mean Pu-concentration in the 0-2 cm-layer was 60±8 (1 SD) pCi ^{239,240}Pu kg^{-1}, i.e. the relative SD of sampling and analysis was 14%. For Am we found 16±3 pCi ^{241}Am kg^{-1}, corresponding to a relative SD of 21%. In the deeper layer the relative SD increased. This was partly due to lower activity, resulting in

Table 8.1.8. Plutonium in sediment samples collected at Barsebäck (location 38) May 7, 1979

Sample collector	Depth in cm	Bq ^{239,240}Pu kg^{-1}	Bq ^{239,240}Pu m^{-2}
P1	0-2	2.5	21
"	2-4	1.92	18.5
"	4-10		
P1	0-10		Σ 39
P2	0-2	2.2	22
"	2-4	1.74	19.2
"	4-10	0.111	4.1
P2	0-10		Σ 45
P3	0-2	1.70	12.2
"	2-4	2.3	20
"	4-10	0.22	7.0
P3	0-10		Σ 40
P4	0-2	2.3	22
"	2-4	1.48	17.0
"	4-6	0.48	5.9
P4	0-6		Σ 45
P5	0-2	2.4	23
"	2-4	2.4	29
"	4-10	0.44	15.5
P5	0-10		Σ 67

a poorer counting statistic, and also from differences in contamination of the deeper layer with surface layer material by the different samplers. In the 2-4 cm layer we found 53±10 pCi $^{239,240}Pu$ (relative SD 19%) and in 4-10 cm 7±4.5 pCi $^{239,240}Pu$ kg^{-1} (65%). The 3 samplers with complete $^{239,240}Pu$ determinations in the 0-10 cm layer gave a mean value of 1.37±0.39 mCi $^{239,240}Pu$ km^{-2} (rel. SD = 29%). This result may be compared with measurements performed in 1976 (Risø Report No. 361, Table 8.5.3)[1)] at seven locations in the Sound, Kattegat, and Great Belt. The mean was then 1.44±0.50 mCi $^{239,240}Pu$ km^{-2} in the 0-15 cm layer. The mean $^{241}Am/^{239,240}Pu$ ratio in the present samples of sediments was 0.27±0.05 (1 SD) (rel. SD: 19%). In soil samples from St. Jyndevad collected 1978 (cf. Risø Report R-403, Table 8.1)[1)] we found a mean ratio of 0.33±0.07, which is not significantly different from that in sediments. However, this does not infer than Am and Pu are removed from the water to the sediments to the same extent, because, in any case, most of the Pu and Am will go into the sediments and minor differences in the behaviour of the two elements could thus be undetected in the Am/Pu ratio in sediments, but rather in, e.g., the water.

8.2. Fucus vesiculosus and Fucus serratus from Danish waters

The International Atomic Energy Agency (IAEA) has supported a study of transuranic elements in Danish waters. In May 1979 samples of Fucus vesiculosus and Fucus serratus were collected from 22 locations in Danish inner waters (cf. Fig. 5.11.2). The samples were analysed by Ge(Li)spectroscopy (cf. 5.11.2) and radiochemically for Pu and Am. The purpose was to see whether or not it is possible to detect any inflow of transuranic elements in the Danish waters along with the ^{137}Cs and ^{134}Cs from Windscale. Furthermore, it was intended to examine if there were significant differences between the two fucoids with respect to the uptake of Pu and Am.

We found no relation between salinity and Pu concentration in fucoids from Danish waters. An analysis of variance shows no

Table 8.2.A. Plutonium in Fucus vesiculosus and Fucus serratus in inner Danish waters collected in April-May 1979

Location	Species	Salinity o/oo	pCi $^{239,240}Pu$ kg^{-1} fresh weight	$^{137}Cs/^{239,240}Pu$	Am/Pu
Hesselø	Fucus serratus	18*	0.77	88	
Dokkedal strand	Fucus vesiculosus	21.7	0.99	48	
Svenskehavn	Fucus vesiculosus	<10*	0.40	106	
Østerbyhavn stenmole (Læsø)	Fucus serratus	25.8	0.68	43	0.32
Grenå mole	Fucus vesiculosus	22.3	0.42	76	
Udbyhøj strand	Fucus vesiculosus	27.3	0.31	161	0.172
Rugård strand	Fucus vesiculosus	26.8	0.48±0.01	151	
Sæby bugt	Fucus vesiculosus	11.7	1.59	29	0.152
Grenå stenmole	Fucus serratus	22*	0.83	67	
Sæby stenmole	Fucus serratus	32.2	0.64±0.06	139	0.151
" "	Fucus vesiculosus	32.2	0.70	149	
Læsø vest	Fucus serratus	23.3	1.03	53	
" "	Fucus vesiculosus	23.3	0.77	40	
Torekov	Fucus serratus	18*	0.68	78	
Anholt havn	Fucus vesiculosus	22*	0.59	83	
Anholt Vesterstrand	Fucus serratus	22*	0.63	47	
Skovshoved havn, læmole	Fucus serratus	17*	1.54	38	
Gilleleje	Fucus vesiculosus	18*	C.39	90	0.153
Helsingør	Fucus serratus	17*	0.63	63	
Mikkelborg	Fucus vesiculosus	17*	0.167	355	
Mean	Fucus vesiculosus		0.62	117	
S.D.	" "		0.40	91	
S.E.	" "		0.12	27	
Mean	Fucus serratus		0.83	68	
S.D.	" "		0.30	31	
S.E.	" "		0.10	10	

*Estimated values (cf. the salinities Table 4.4.1).

Table 8.7.8. Plutonium in Fucus vesiculosus and Fucus serratus in inner Danish waters collected in April-May 1979

Location	Species	Salinity o/oo	Bq $^{239,240}Pu$ kg^{-1} fresh weight
Hesselø	Fucus serratus	18*	0.028
Dokkedal strand	Fucus vesiculosus	21.7	0.037
Svenskehavn	Fucus vesiculosus	<10*	0.0148
Østerbyhavn stenmole	Fucus serratus	25.8	0.025
Grenå mole	Fucus vesiculosus	22.3	0.0155
Udbyhøj strand	Fucus vesiculosus	27.3	0.0115
Rugård strand	Fucus vesiculosus	26.8	0.0178±0.0004
Sæby bugt	Fucus vesiculosus	11.7	0.059
Grenå stenmole	Fucus serratus	22*	0.031
Sæby stenmole	Fucus serratus	32.2	0.024±0.002
" "	Fucus vesiculosus	32.2	0.026
Læsø vest	Fucus serratus	23.3	0.038
" "	Fucus vesiculosus	23.3	0.028
Torekov	Fucus serratus	18*	0.025
Anholt havn	Fucus vesiculosus	22*	0.022
Anholt Vesterstrand	Fucus serratus	22*	0.023
Skovshoved havn, læmole	Fucus serratus	17*	0.057
Gilleleje	Fucus vesiculosus	18*	0.0144
Helsingør	Fucus serratus	17*	0.023
Mikkelborg	Fucus vesiculosus	17*	0.0062
Mean	Fucus vesiculosus		0.023
S.D.	" "		0.015
S.E.	" "		0.004
Mean	Fucus serratus		0.031
S.D.	" "		0.011
S.E.	" "		0.004

*Estimated values (cf. the salinities Table 4.4.1).

significant difference between the Pu levels in the two fucoid species.

The $^{241}Am/^{239,240}Pu$ mean ratio is 0.19±0.07 (1 SD). This is lower than the ratio found in sediments and accumulated fallout (cf. 8.1) suggesting that the Am/Pu ratio in sea water is lower than in sediments or/and that fucoids prefer Pu to Am.

The measurements of transuranics in Danish fucoids collected during May 1979 thus show no evident indication of Windscale plutonium or americium in Danish waters.

The radiochemical analyses for the α-emitters indicate a considerable accumulation of thorium isotopes in the seaweeds.

9. MEASUREMENTS OF BACKGROUND RADIATION IN 1979

by L. Bøtter-Jensen and S.P. Nielsen

9.1. Instrumentation

Measurements of the background radiation were made with thermoluminescence dosimeters (TLD's)[23] a mobile Ge(Li) spectrometer system[24], a high pressure ionisation chamber (Reuter-Stokes RSS-111), and a NaI(Tl) detector.

9.2. State experimental farms

The State experimental farms are situated as shown in Fig. 4.2. The results of the TLD measurements are shown in Table 9.2.1. The results of the NaI(Tl) detector measurements are shown in Table 9.2.2.

The γ-background measured with the NaI(Tl) detector in four groups of sampling stations is shown in Fig. 9.2.1 from 1962 to

Table 9.2.1. TLD-measurements of the background radiation (integrated over 11 months and normalized to $\mu R\ h^{-1}$) at the state experimental farms in 1978-79

	October 1978-September 1979
Tylstrup	7.4
Studsgård	6.6
Ødum	8.4
Askov	7.7
St. Jyndevad	6.3
Blangstedgård	8.2
Tystofte	8.3
Abed	7.9
Mean	7.6

Table 9.2.2. Terrestrial exposure rates at the State experimental farms in 1979 measured with the NaI(Tl) detector ($\mu R\ h^{-1}$)

Location	June	Sep	Nov	Mean
Tylstrup	3.1	3.6	3.2	3.3
Studsgård	2.6	3.1	(3.0)	(2.9)
Odum	3.9	4.8	(4.5)	(4.4)
Askov	3.3	3.7	(3.6)	(3.6)
St. Jyndevad	2.2	2.3	(2.4)	(2.3)
Blangstedgård	4.5	4.6	(4.7)	(4.6)
Ledreborg	4.6	5.2	5.2	5.0
Tystofte	4.2	4.1	4.5	4.3
Abed	5.1	5.2	5.2	5.2
Tornbygård	5.4	(5.7)	(5.7)	(5.6)
Mean	3.9	(4.2)	(4.2)	(4.1)

Figures in brackets calculated from VAR3[12].

1976 and in Fig. 9.2.2 since 1977. The data in Fig. 9.2.2 show terrestrial exposure rates, which agree with measurements made with other instruments. The levels in Fig. 9.2.1, however, are significantly higher than in Fig. 9.2.2, but this change coincides with a modification of the instrument and of the calculation of the results. Therefore, the difference in γ-background levels in Figs. 9.2.1 and 9.2.2 is partly caused by the instruments and partly by the lack of correction in previous years for γ-background of cosmic origin and for ^{40}K from the detector assembly.

In June, a special survey of the background radiation was made in South Jutland in collaboration with a measuring team from SCPRI (le Service Central de Protection contre les Rayonnements Ionisants) in France. The SCPRI team was making a field study for intercomparison purposes in the frontier areas of countries neighbouring the Federal Republic of Germany. The team used a scintillation exposure rate meter developed by the Physikalish-Technischen Bundesanstalt in FRG.

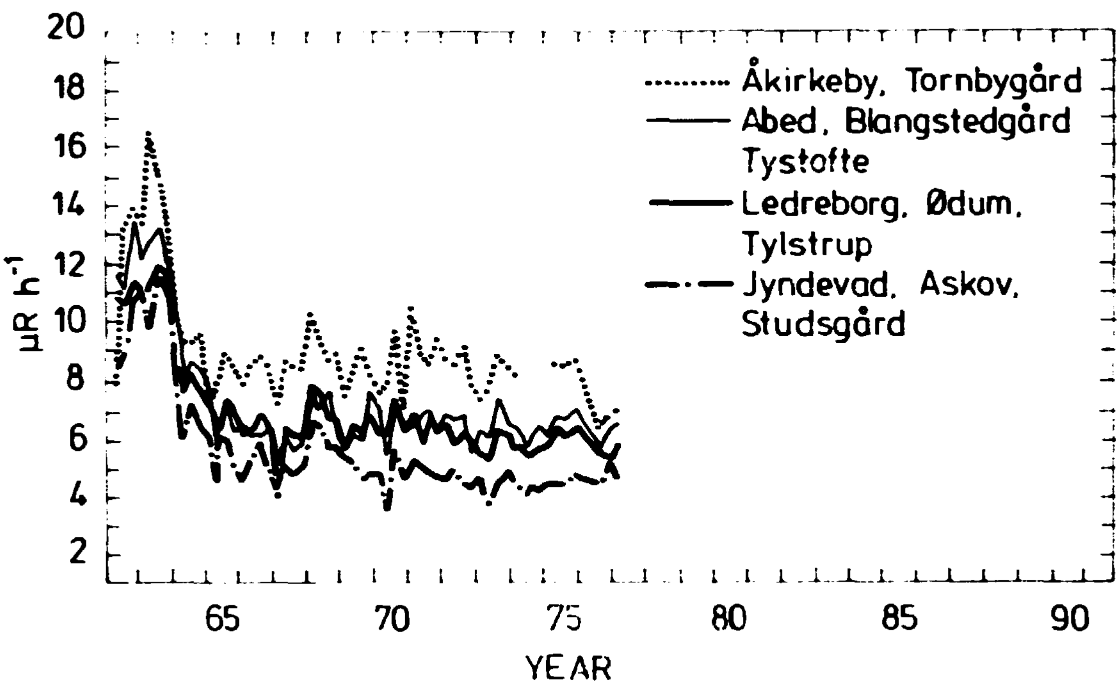


Fig. 9.2.1. Terrestrial exposure rates at the State experimental farms in 1962-1976 measured with the NaI(Tl) detector (μR h^{-1}).

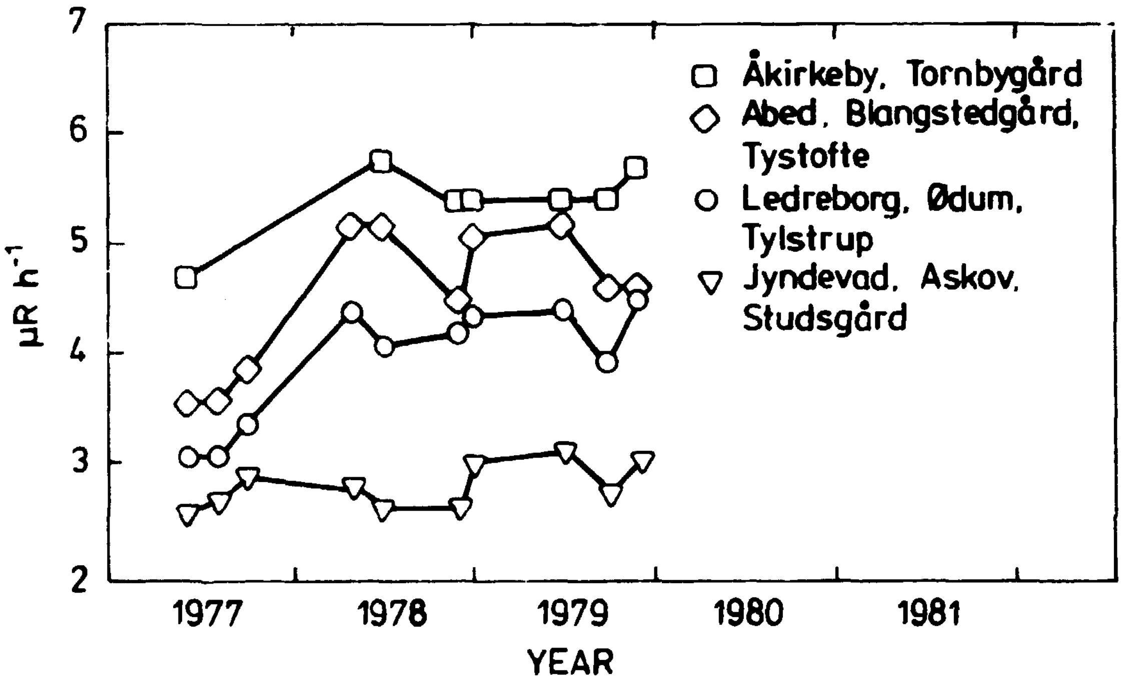


Fig. 9.2.2. Terrestrial exposure rates at the State experimental farms in 1977-1979 measured with the NaI(Tl) detector (μR h^{-1}).

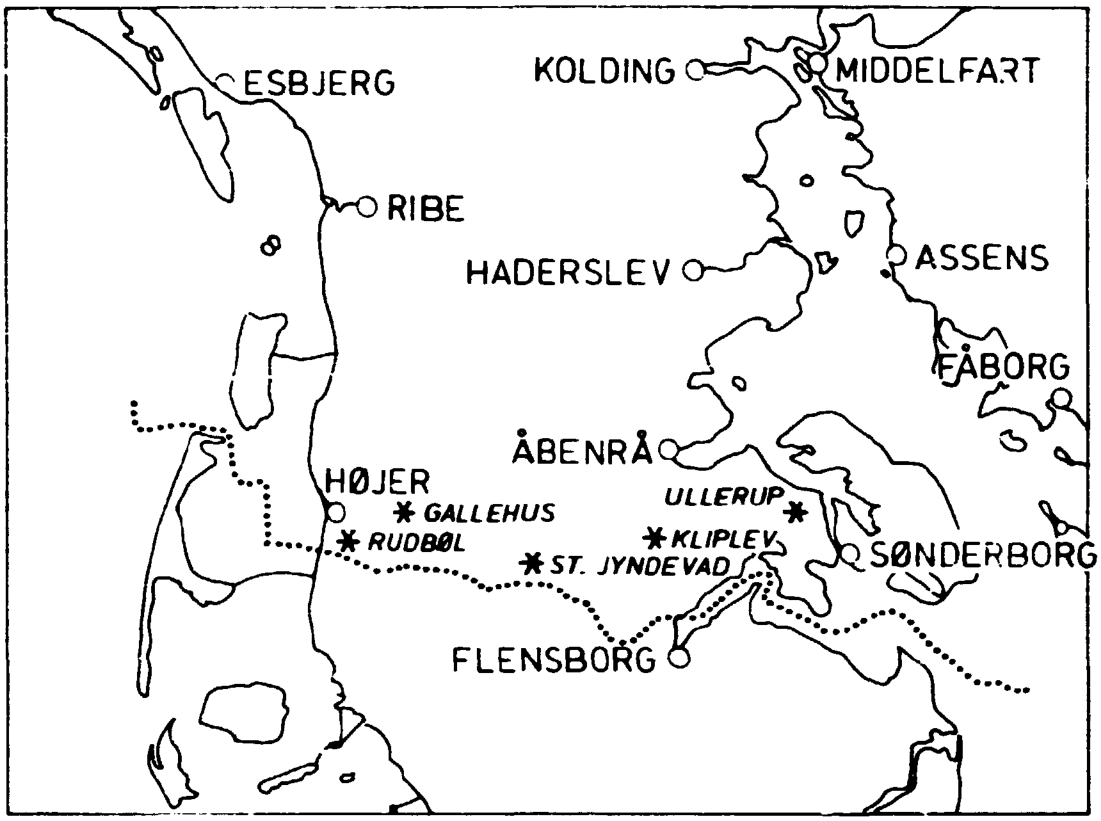


Fig. 9.2.3. Locations for measurements in South Jutland.

The measurements were carried out at 5 locations near the Danish-German border, Fig. 9.2.3. Ge(Li) spectroscopic measurements were made at two of those locations and the results are shown together with those from Ledreborg State experimental farm found on another occasion and noted in Tables 9.2.3 and 9.2.4. The results from the ionisation chamber, the NaI(Tl) detector and the scintaillation exposure rate meter are shown in Table 9.2.5. The response of the scintillation exposure rate meter to the cosmic secondaries was found from linear regression with the ionisation chamber results to be 1.1 μR h^{-1}±0.1 (SD). This value was later confirmed by Professor Moroni from the SCPRI.

Table 9.2.3. Terrestrial exposure rates estimated from field spectroscopic measurements (μR h^{-1})

Location	^{40}K	^{226}Ra	^{232}Th	^{137}Cs	Total
Ledreborg	2.2	0.9	1.4	0.1	4.6
St. Jyndevad	1.0	0.3	0.3	0.3	1.9
Ullerup	2.4	0.8	1.3	0.1	4.6

Table 9.2.4. Radionuclides in the soil estimated from field spectroscopic measurements (pCi g^{-1})

Location	^{40}K	^{226}Ra	^{232}Th	^{137}Cs*
Ledreborg	12.0	0.46	0.51	0.17
St. Jyndevad	5.4	0.16	0.11	0.43
Ullerup	12.0	0.41	0.47	0.20

*Assuming a homogeneous distribution 0-20 cm.

Table 9.2.5. Measurements of background radiation in South Jutland (μR h^{-1})

Location	Ionization chamber	NaI(Tl) detector	Scintillation exposure rate meter
St. Jyndevad	5.5	1.5	3.0
Gallehus	6.5	2.7	3.9
Rudbøl	7.5	3.9	5.2
Kliplev	5.9	2.2	3.2
Ullerup	8.2	4.5	5.4

Table 9.2.6. Terrestial exposure rates in South Jutland measured with different instruments (μR h^{-1})

Instrument	St. Jynde-vad	Galle-hus	Rudbøl	Kliplev	Ullerup
Ionization chamber	1.9	2.9	3.9	2.3	4.6
NaI(Tl) detector	1.5	2.7	3.9	2.2	4.5
Scintillation exposure rate meter	1.9	2.8	4.1	2.1	4.3
Ge(Li) spectroscopy	1.9	-	-	-	4.6

For comparison, the results in term of terrestrial exposure rates are shown in Table 9.2.6, where the ionisation chamber data are reduced with 3.6 μR h^{-1} and the scintillation exposure rate meter data with 1.1 μR h^{-1}. It is noted that the results agree well within the expected limits of precision. A precision of less than 0.1 μR h^{-1} was expected from the ionisation chamber and the Ge(Li) spectroscopy system and more than this for the NaI(Tl) detector and the scintillation exposure rate meter.

9.3. Risø environment

The five zones around Risø are located as shown in Fig. 9.3.1, the results of the TLD measurements are shown in Table 9.3.1 and the results of the NaI(Tl) detector measurements are shown in Table 9.3.2.

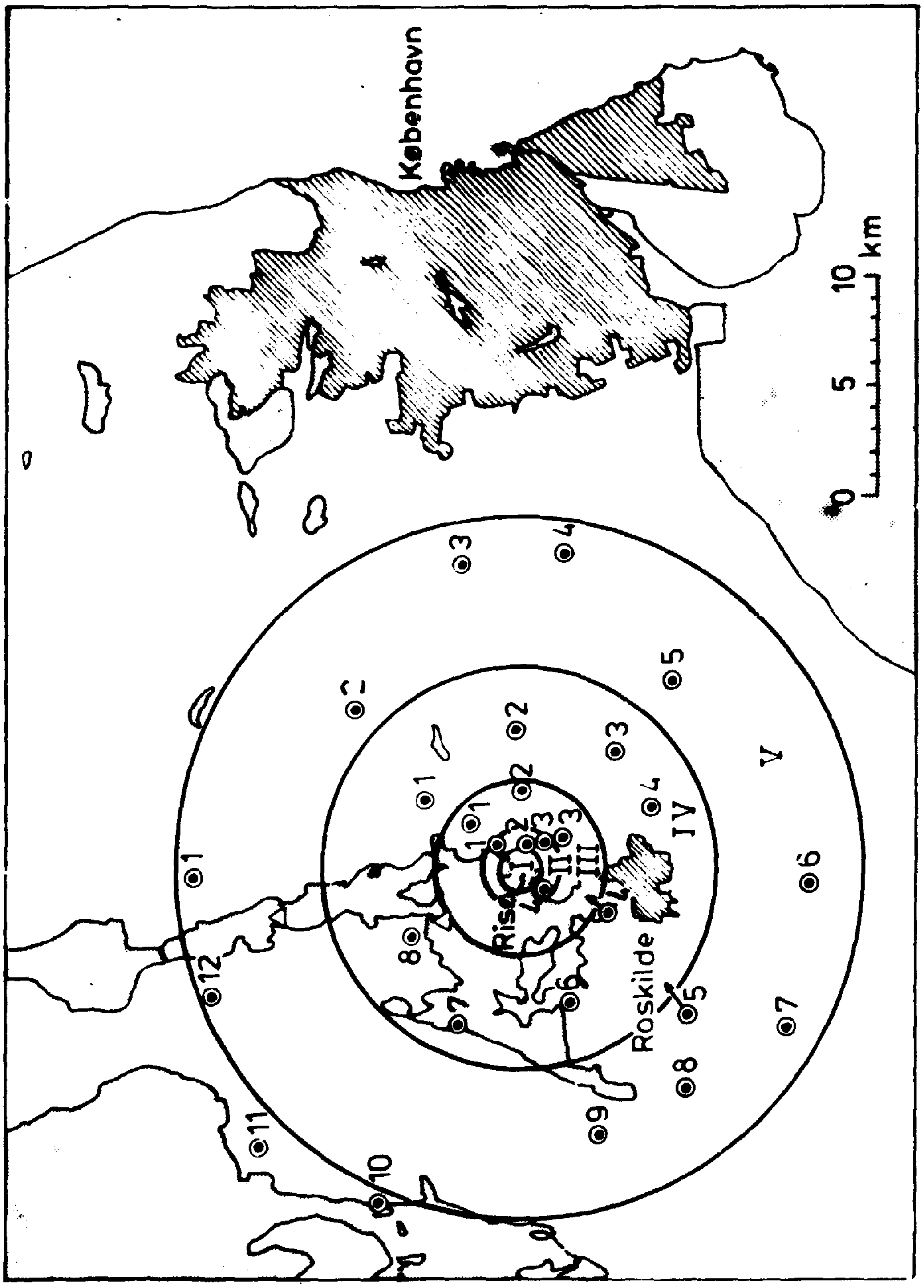


Fig. 9.3.1. The environment of Risø. Locations for measurements of the background radiation.

Table 9.3.1. TLD-measurements of the background radiation (integrated over 11 months and normalized to μR h^{-1}) in five zones (I-V) around Risø in 1978-79

Risø zone	Location	October 1978-September 1979
I	1	8.4
"	2	8.7
"	3	22.8
"	4	9.7
"	5	15.9
Mean		13.1
II	1	8.2
"	2	-
"	3	7.8
"	4	8.6
Mean		8.2
III	1	9.2
"	2	8.7
"	3	9.2
Mean		9.0
IV	1	8.3
"	2	8.2
"	3	8.6
"	4	9.1
"	5	6.9
"	6	8.9
"	7	9.1
Mean		8.4
V	1	8.1
"	2	9.1
"	3	8.0
"	4	8.4
"	5	8.9
"	6	8.9
"	7	8.4
"	8	7.6
"	9	9.0
"	10	-
Mean		8.5

<u>Table 9.3.2</u>. Terrestrial exposure rates at the Risø zones in 1979 measured with the NaI(Tl) detector ($\mu R\ h^{-1}$)

Risø zone	Location	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Mean
I	1	4.3	5.9	4.1	4.5	4.7	5.1	5.3	6.0	4.8	4.7	5.6	5.6	5.1
"	2	7.0	6.4	6.0	6.5	6.5	6.3	6.8	7.1	6.2	7.1	6.9	7.0	6.6
"	3	73.6	78.0	69.5	77.7	80.3	73.8	76.5	78.8	70.6	78.5	92.0	82.7	76.8
"	4	6.5	5.2	4.1	5.2	5.1	6.0	5.3	5.1	5.8	6.1	6.2	5.8	5.5
"	5	16.6	14.2	12.9	18.7	20.1	19.3	18.5	20.2	31.5	15.6	17.2	14.1	18.2
Mean		20.3	21.9	19.3	22.5	23.3	22.1	22.5	23.4	23.8	22.4	23.4	23.6	22.3
II	1			4.5		4.4	4.7		4.8	4.6	4.7			4.6
"	2			5.3		5.0	5.4		5.4	5.5	5.7			5.4
"	3			4.0		3.3	4.7		4.0	4.4	5.1			4.3
"	4			4.9		4.6	4.7		4.4	4.5	5.3			4.7
Mean				4.7		4.5	4.9		4.7	4.8	5.2			4.8
III	1			5.9		5.2	5.9		5.6	5.5	5.6			5.6
"	2			5.1		4.6	4.9		4.9	5.1	5.2			5.0
"	3			4.5		4.4	4.6		4.8	4.7	5.0			4.7
Mean				5.2		4.7	5.1		5.1	5.1	5.3			5.1
IV	1					3.7				4.2		4.1		
"	2	4.8				4.7				4.9		5.2		
"	3	4.8				4.7				5.0		5.1		
"	4	4.6				3.9				4.8		4.7		
"	5	3.3				4.2				4.6		4.7		
"	6	4.6				4.3				4.2		5.7		
"	7					4.7				4.6		4.1		
Mean		(4.4)				4.3				4.6		4.8		
V	1	4.6				4.7				4.2		4.8		
"	2	5.3				5.3				5.8		5.8		
"	3					3.9				4.4		4.7		
"	4					4.2				4.7		4.5		
"	5					4.3				4.8		4.8		
"	6	3.8				4.5				4.7		5.1		
"	7	4.8				4.7				5.5		4.7		
"	8					4.2				4.4		4.6		
"	9	4.6				4.1				5.0		5.1		
"	10					3.6				4.0		4.2		
Mean		(4.6)				4.4				4.8		4.8		

In the Risø environment a few Ge(Li) spectroscopic measurements were made in Zone 1. The only artificial radioisotopes detected here were fallout ^{137}Cs and ^{41}A. The latter originates from routine operation of the reactor DR 3.

9.4. Gylling Næs environment

The Gylling Næs environment (a potential nuclear power plant site) is routinely monitored with TLD's, and the results from three zones around the site are given in Table 9.4.1. The locations are shown in Fig. 9.4.1.

Table 9.4.1. TLD-measurements of the background radiation (integrated over 11 months and normalized to μR h^{-1}) in four zones (I-IV) around the Gyllingnæs site in 1978-79

Gyllingnæs zone	Location	October 1978–September 1979
I	1	7.5
"	2	-
"	3	8.4
"	4	7.7
Mean		7.9
II	1	8.4
"	2	8.6
Mean		8.5
III	1	7.5
"	2	7.9
"	3	8.5
"	4	6.6
"	5	8.6
Mean		7.8
IV	1	8.2
"	2	8.3
"	3	8.1
Mean		9.2

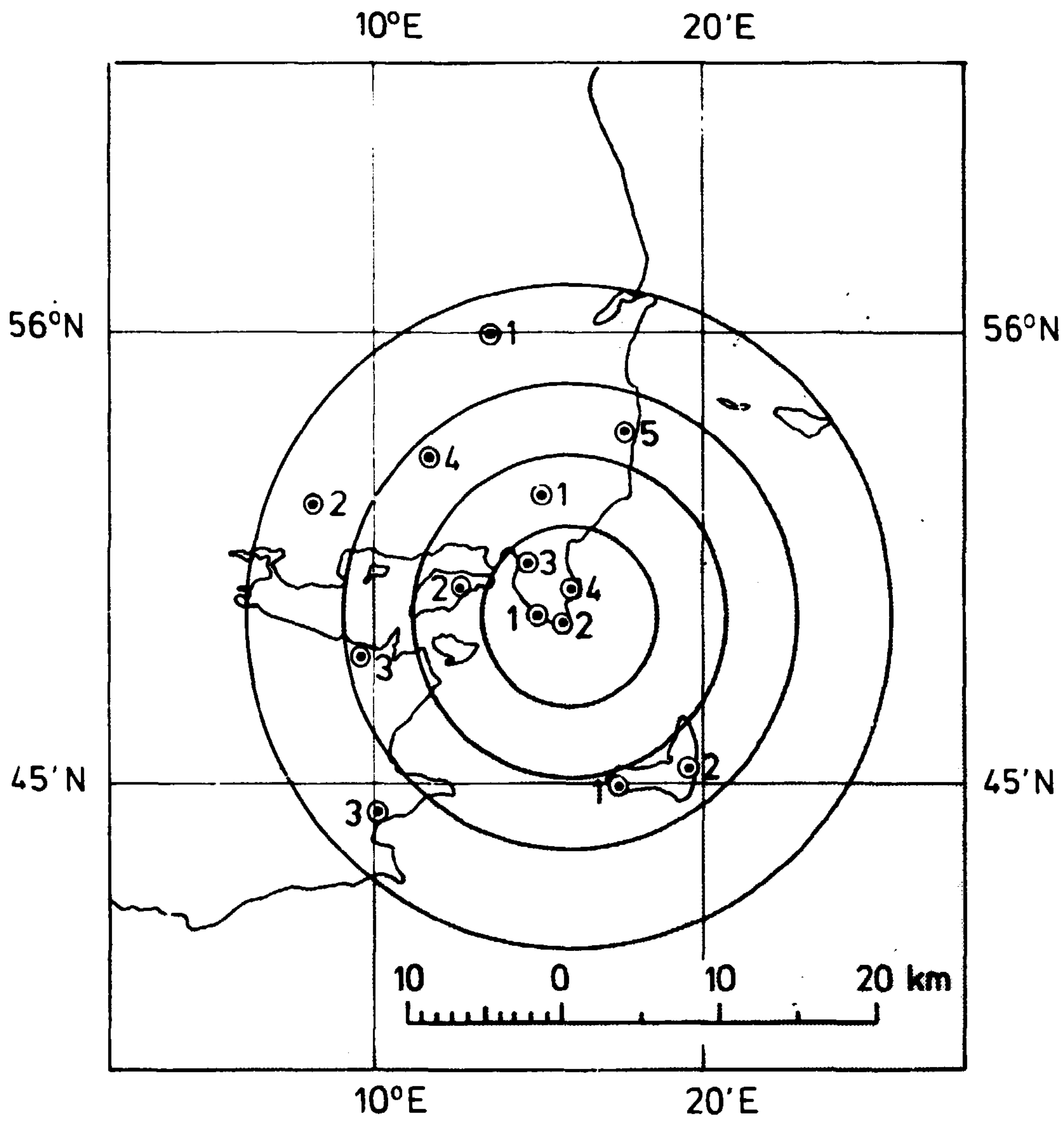


Fig. 9.4.1. The environment of Gylling Næs. Locations for measurements of the background radiation.

9.5. Great Belt and Langeland Belt areas

Locations on both shores of the Great Belt and the Langeland Belt (an international shipping route) are likewise routinely monitored with TLD's; the results and locations are shown in Table 9.5.1 and Fig. 9.5.1, respectively.

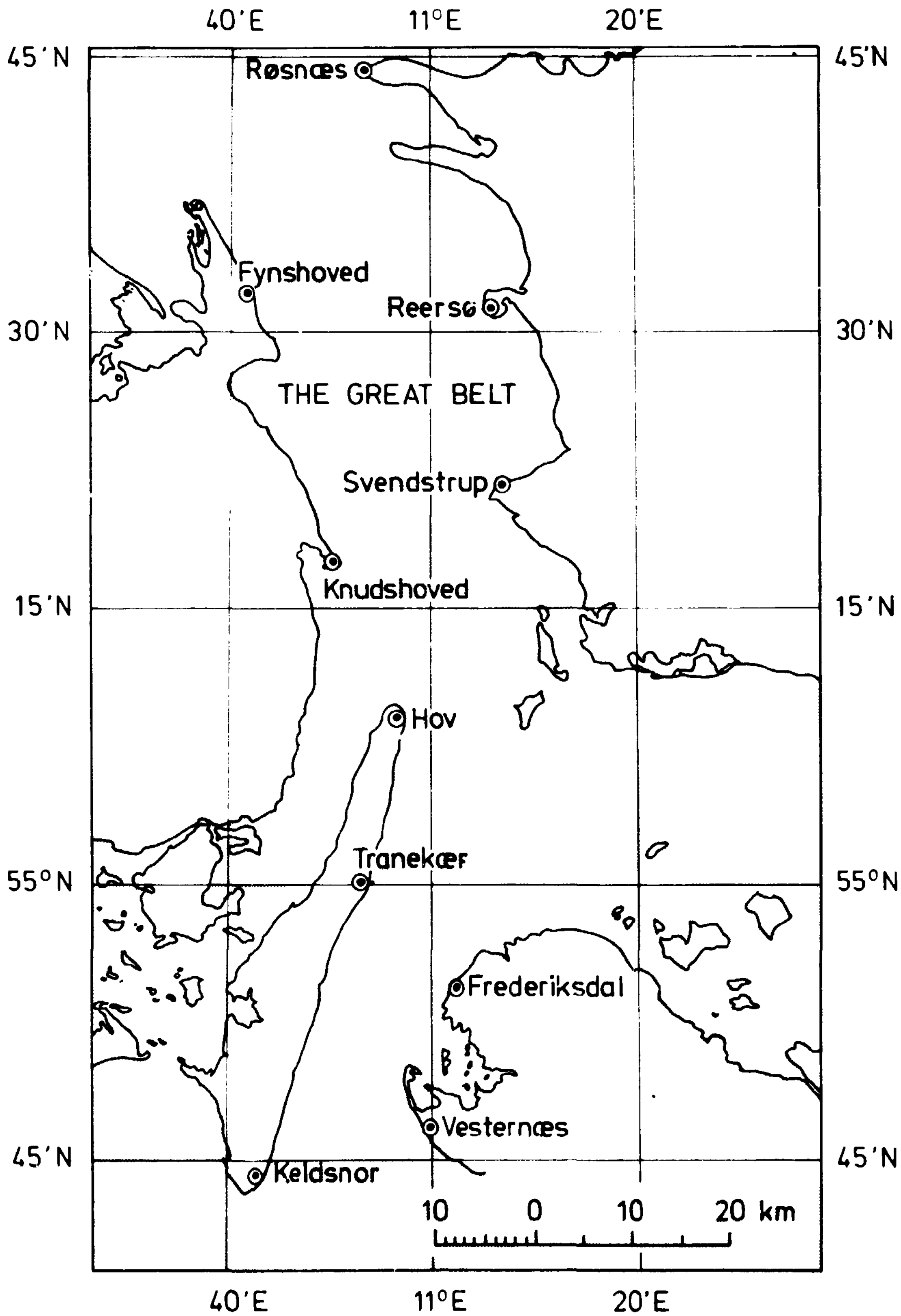


Fig. 9.5.1. The coasts of the Great Belt. Locations for measurements of the background radiation.

Table 9.5.1. TLD-measurements of the background radiation (integrated over 11 months and normalized to μR h^{-1}) along the coasts of the Great Belt and Langeland Belt in 1978-79

Location	October 1978-September 1979
Røsnæs	7.4
Reersø	9.1
Svendstrup	7.9
Frederiksdal	9.4
Vesternæs	8.4
Kelds Nor	9.4
Tranekær	9.1
Hov	7.4
Fyns Hoved	8.1
Knuds Hoved	8.4
Mean	8.5

9.6. The Baltic island, Bornholm

Locations on the island of Bornholm have been monitored with TLD's during winter 1978/79 and summer 1979. The results and locations are shown in Table 9.6.1 and Fig. 9.6.1, respectively.

Table 9.6.1. TLD-measurements of the background radiation (integrated over 7 and 5 months respectively and normalized to μR h^{-1}) on the island Bornholm in 1978-79

Location	Winter 1978/1979	Summer 1979	Mean
1	9.1	9.9	9.5
2	6.8	6.7	6.8
3	7.3	7.2	7.3
4	8.4	9.8	9.1
5	14.4	14.3	14.4
Mean	9.2	9.6	9.4

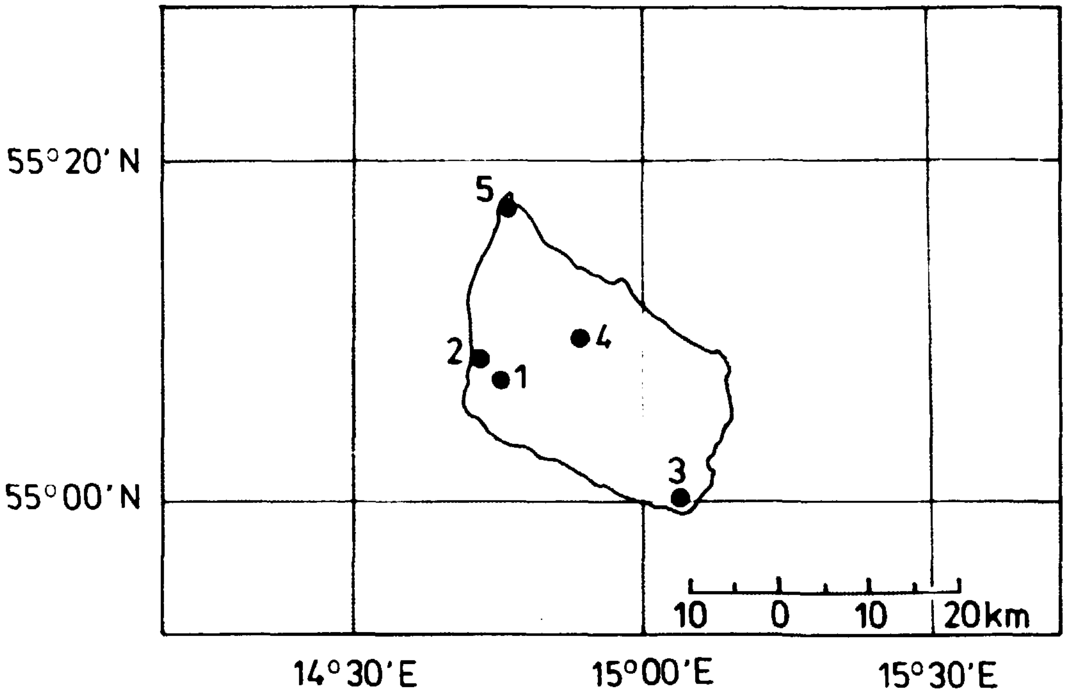


Fig. 9.6.1. Locations for measurements on Bornholm.

9.7. Discussion

It should be noted that the reported TL data are results from a one-year integration period and that there is excellent agreement with the results from previous years where the integration period was only 6 months.

10. CONCLUSION

10.1. Environmental monitoring at Risø, Barsebäck and Ringhals

No radioactive contamination of the environment originating from the operation of the research establishment was ascertained outside Risø in 1979. As in previous years, the variations in contamination level were independent of the distance of the sampling locations from Risø.

Benthic brown algae, mussels and fish collected at the Swedish nuclear plants at Barsebäck and Ringhals were analysed for radioactive pollution. Transfer factors from releases of various radionuclides to Fucus were calculated. The radioactive contamination of the marine environment due to the operation of the Swedish nuclear power plants resulted into doses of less than 1 mrem per year to any individual eating 20 kg mussel and 100 kg fish per year.

10.2. Nuclear-weapon debris in the abiotic environment

The mean content of ^{90}Sr in air collected in 1979 was 0.4 fCi ^{90}Sr m^{-3}, i.e. approx. 0.3 times the 1978 level. The average fallout at the State experimental farms in 1979 was 0.17 mCi ^{90}Sr km^{-2} or 0.4 times the 1978 figure, and the mean concentration of ^{90}Sr in rain water was 0.27 pCi ^{90}Sr l^{-1}.

By the end of 1979 the accumulated fallout was approx. 48 mCi ^{90}Sr km^{-2}. The corresponding ^{137}Cs was estimated at 77 mCi km^{-2}.

In agreement with the greater precipitation in that part of the country, fallout levels in Jutland were 15-25% higher than levels found in eastern Denmark.

The median level of ^{90}Sr in Danish ground water was 5 fCi ^{90}Sr l^{-1}. Fresh water from streams contained 0.3 pCi ^{90}Sr l^{-1} and lake water showed a countrywide mean level of 1.2 pCi ^{90}Sr l^{-1}.

The population-weighted mean level in Danish drinking water was 22 fCi $^{90}Sr\ l^{-1}$.

Inner Danish surface waters (salinity 16 o/oo) contained 0.6 pCi $^{90}Sr\ l^{-1}$ and 1.0 pCi $^{137}Cs\ l^{-1}$.

10.3. Fallout nuclides in the human diet

The mean level of ^{90}Sr in Danish milk was 2.9 S.U., and the mean content of ^{137}Cs was approx. 4.8 pCi $^{137}Cs\ l^{-1}$.

The 1979 ^{90}Sr and ^{137}Cs levels were 0.9 and 0.7 times respectively the levels found in milk produced in 1978.

The ^{90}Sr mean content in grain from the 1979 harvest was 22 pCi $^{90}Sr\ kg^{-1}$. The ^{137}Cs mean content in grain was 10 pCi $^{137}Cs\ kg^{-1}$. The ^{90}Sr level in grain from the 1979 harvest was 10% lower than the level found in the 1978 harvest, and ^{137}Cs was 0.4 times the 1978 level.

The mean contents of ^{90}Sr and ^{137}Cs in Danish vegetables collected in 1979 were 6.9 pCi $^{90}Sr\ kg^{-1}$ (23 S.U.) and 1.7 pCi $^{137}Cs\ kg^{-1}$, respectively, and in fruits 0.5 pCi $^{90}Sr\ kg^{-1}$ and 1.9 pCi $^{137}Cs\ kg^{-1}$; potatoes contained 2.0 pCi $^{90}Sr\ kg^{-1}$ and 2.1 pCi $^{137}Cs\ kg^{-1}$.

The mean levels of ^{90}Sr and ^{137}Cs in total-diet samples collected in 1979 were 4.3 S.U., or 7 pCi $^{90}Sr\ (day)^{-1}$ and 13 pCi $^{137}Cs\ (day)^{-1}$, respectively. From analyses of the individual diet components, the ^{90}Sr level in the Danish average diet was estimated to be 4.0 S.U. and the ^{137}Cs intake to be 14 pCi $^{137}Cs\ (day)^{-1}$. The levels of ^{90}Sr and ^{137}Cs in the Danish total diet consumed in 1979 were 10% and 25% lower respectively than the levels observed in 1978.

Grain products contributed 37% and milk products 32% to the total ^{90}Sr intake; 28% of the ^{137}Cs in the diet originated from grain products, 19% from meat, and 16% from milk products. Fish contributed with 22% to the ^{137}Cs diet intake, of this four fifth were due to radiocesium from Windscale.

Both ^{90}Sr and ^{137}Cs diet levels were on the average higher in Jutland than in eastern Denmark.

10.4. Strontium-90 and Cesium-137 in humans

The ^{90}Sr mean content in human bone (vertebrae) collected in 1979 was about 1 S.U. in adults. The younger age groups showed lower concentrations (0.7 S.U.).

Whole-body measurements of ^{137}Cs have been suspended due to the low ^{137}Cs concentrations in man. The estimated level in 1979 was 12 pCi ^{137}Cs $(g\ K)^{-1}$.

10.5. Tritium in environmental samples

Tritium levels varied between 0.2 and 0.4 nCi l^{-1} in rain water and between 0.03 and 0.34 nCi l^{-1} in ground water. Danish drinking water showed a population-weighted mean value of 0.1 nCi l^{-1} and lake and stream water contained 0.2 nCi l^{-1}. The tritium concentration in sea water varied inversely as the salinity.

10.6. Plutonium in environmental samples

Plutonium and americium were determined in sediments and seaweed. In sediments the mean $^{241}Am/^{239,240}Pu$ ratio was 0.27 or similar to that in soil samples. In fucoids the mean ratio was 0.19 suggesting that the Am/Pu ratio in sea water is lower than in sediments.

10.7. Background radiation

The average total background exposure rate measured with the ionisation chamber at the State experimental farms was 7.6 μR h^{-1} of which 3.6 μR h^{-1} originates from the secondary cosmic radiation and the remaining 4 μR h^{-1} from terrestrial sources. This result is in accordance with that observed in 1978.

ACKNOWLEDGEMENTS

The authors wish to thank Miss Anna Holm Pedersen, Mrs. Karen Mandrup Jensen, Miss Karen Wie Nielsen, Mrs. Jytte Lene Clausen, Mrs. Anna Madsen, Mrs. Pearl Baade Pedersen, Mrs. Alice Kjølhede, Mrs. Helle Porsdal, Mrs. Oda Brandstrup, Mrs. Elise Gudmundsen, Mrs. Else Sørensen and Mr. Michael Brandt Svendsen for their conscientious performance of the analyses. We are grateful to Mr. Peder Kristiansen and Mr. Gunnar Bitsch for collection of the samples and performance of the γ-background measurements. We thank Mrs. Lis Sørensen for careful work with the TL dosimeters.

We are specially indebted to the staffs of the eleven State experimental farms at Tylstrup, Ødum, Studsgård, Borris, Askov, St. Jyndevad, Blangstedgård, Tystofte, Ledreborg, Abed, and Åkirkeby, who have continued to supply us with a number of the most important samples dealt with in this report.

Finally we convey our thanks to M/S "Nordsøen" in Esbjerg and M/S "Nordjylland" in Skagen for the sea water samples received from the North Sea.

Appendix A. Calculated fallout in Denmark in 1979

Zone		mm precipitation in 1979	mCi ^{90}Sr km^{-2} in 1979	Accumulated mCi ^{90}Sr km^{-2} by the end of 1979
I:	N. Jutland	837 (848)	0.174	54
II:	E. Jutland			
III:	W. Jutland			
IV:	S. Jutland			
V:	Funen	632 (620)	0.160	43
VI:	Zealand			
VII:	Lolland-Falster			
VIII:	Bornholm	650 (699)	0.136	-
Area-weighted mean		774 (779)	0.17	51

The amounts of precipitation were obtained from ref. 9. The ^{90}Sr deposition was estimated from 4.2 and appendix D.

The precipitations in brackets were the mean of values measured by the Meteorological Institute at the State experimental farms: Jutland: Tylstrup, Ødum, Studsgård, Askov, St. Jyndevad; The Islands: Blangstedgård, Tystofte, Ledreborg, Abed; Bornholm: Åkirkeby.

APPENDIX B. Statistical information

<table>
<tr><th colspan="2">Zone</th><th>Area in km^2
15) 1971</th><th>Population in thousands
28) 1976</th><th>Annual milk production in mega-kg
14) 1971</th><th>Annual wheat production in mega-kg
13) 1972</th><th>Annual rye production in mega-kg
13) 1972</th><th>Annual potato production in mega-kg
13) 1972</th><th>Vegetable area in km^2
13) 1972</th></tr>
<tr><td>I:</td><td>N. Jutland</td><td>6,171</td><td>471</td><td>911</td><td rowspan="4">145</td><td rowspan="4">155</td><td rowspan="4">609</td><td rowspan="4">14</td></tr>
<tr><td>II:</td><td>E. Jutland</td><td>7,561</td><td>881</td><td>1,258</td></tr>
<tr><td>III:</td><td>W. Jutland</td><td>12,104</td><td>687</td><td>926</td></tr>
<tr><td>IV:</td><td>S. Jutland</td><td>3,929</td><td>245</td><td>572</td></tr>
<tr><td>V:</td><td>Funen</td><td>3,486</td><td>446</td><td>393</td><td></td><td></td><td></td><td></td></tr>
<tr><td>VI:</td><td>Zealand</td><td>7,435</td><td>2,165*</td><td>395</td><td rowspan="3">448</td><td rowspan="3">71</td><td rowspan="3">100</td><td rowspan="3">73</td></tr>
<tr><td>VII:</td><td>Lolland-Falster</td><td>1,795</td><td>123</td><td>68</td></tr>
<tr><td>VIII:</td><td>Bornholm</td><td>588</td><td>47</td><td>39</td></tr>
<tr><td colspan="2">Total</td><td>43,069</td><td>5,065</td><td>4,562</td><td>593</td><td>226</td><td>709</td><td>87</td></tr>
</table>

*1,270,000 people were living in Greater Copenhagen and 895,000 in the remaining part of Zealand.

APPENDIX C

The mean ratio between observed and predicted values was 1.10± 0.50 (1 SD) for ^{90}Sr and 0.84±0.24 for ^{137}Cs. In general, the prediction models underestimated the ^{90}Sr levels in 1979, while the ^{137}Cs concentrations were overestimated.

In case of ^{137}Cs the calculation of the ^{137}Cs deposition from the ^{90}Sr deposition (cf. Table 4.2.1) was revised as compared to the previous years, when we assumed the $^{137}Cs/^{90}Sr$ ratio equal to 1.6. For the 1979 calculations we have applied the $^{137}Cs/^{90}Sr$ ratios observed in air (cf. Tables 4.1.1 and 4.1.2).

Appendix C.1. Comparison between observed and predicted ^{90}Sr levels in environmental samples collected in 1979

Sample	Location	Unit	Observed	Predicted	Obs./pred.	Model in reference (21)
Dried milk*	Jutland	pCi ^{90}Sr (g Ca)$^{-1}$	3.3	3.9	0.85	C.3.2.1 No. 1
" "	Islands	- " -	2.4	2.0	1.20	- " - No. 3
Rye	Jutland	pCi ^{90}Sr kg^{-1}	25	15.5	1.61	C.2.2.1 No. 1
"	Islands	- " -	16.1	5.5	2.93	- " - No. 3
Barley	Jutland	- " -	30	21	1.43	- " - No. 4
"	Islands	- " -	13.4	9.7	1.38	- " - No. 6
Wheat	Jutland	- " -	27	21	1.29	- " - No. 8
"	Islands	- " -	13.7	9.8	1.40	- " - No.10
Oats	Jutland	- " -	31	42	0.74	- " - No.12
"	Islands	- " -	17.8	20	0.89	- " - No.13
Rye bread	Denmark	- " -	14.6	15.6	0.94	C.2.3.1 No. 1
White bread	"	- " -	4.4	4.3	1.02	- " - No. 2
Potatoes	Jutland	- " -	1.8	3.1	0.58	C.2.5.1 No. 8
"	Islands	- " -	2.2	2.8	0.79	- " - No.10
Cabbage	Jutland	- " -	12.2	9.9	1.23	- " - No. 1
"	Islands	- " -	6.2	8.4	0.74	- " - No. 3
Carrot	Jutland	- " -	9.8	16.8	0.58	- " - No. 5
"	Islands	- " -	6.4	6.8	0.94	- " - No. 6
Apples	Denmark	- " -	0.52	0.54	0.96	- " - No.13
Pork	"	- " -	1.4	0.86	1.63	C.3.4.1 No. 3
Beef	"	- " -	0.34	1.12	0.30	- " - No. 1
Eggs	"	- " -	1.14	0.56	2.04	C.3.6.1 No. 6
Total diet C	"	pCi ^{90}Sr (g Ca)$^{-1}$	4.3	5.2	0.83	C.4.2.1 No. 1
" " P	"	- " -	4.0	4.6	0.88	- " - No. 7
Human bone > 29 yr	"	- " -	1.01	1.21	0.84	C.4.3.1 No.13
Whole year grass	Islands	- " -	26	20	1.28	C.2.4.1 No. 1
Fucus Vesiculosus	"	- " -	11.8	13.6	0.87	C.2.7.1 No. 3
Zostera Marina	"	- " -	2.0	2.5	0.80	- " - No. 1
Ground water	Denmark	fCi ^{90}Sr l^{-1}	10.3	10.0	1.03	C.1.4.1 No. 1

*May 1979 - April 1980 ("milk year" (21)).

Appendix C.2. Comparison between observed and predicted ^{137}Cs levels in environmental samples collected in 1979

Sample	Location	Unit	Observed	Predicted	Obs./pred.	Model in reference (21)
Dried milk*	Jutland	pCi ^{137}Cs (g K)$^{-1}$	3.2	2.7	1.18	C.3.2.2 No. 1
" "	Islands	- " -	1.5	1.8	0.83	- " - No. 3
Rye	Jutland	pCi ^{137}Cs kg^{-1}	14.7	16.5	0.89	C.2.2.4 No. 2
"	Islands	- " -	9.7	14.4	0.67	- " - No. 3
Barley	Jutland	- " -	11.9	12.1	0.98	- " - No. 4
"	Islands	- " -	7.5	9.7	0.77	- " - No. 5
Wheat	Jutland	- " -	10.0	12.2	0.82	- " - No. 6
"	Islands	- " -	6.1	8.3	0.73	- " - No. 7
Oats	Jutland	- " -	11.6	10.0	1.16	- " - No. 8
"	Islands	- " -	7.6	9.1	0.84	- " - No. 9
Rye bread	Denmark	- " -	23	43.8	0.52	C.2.3.1 No. 4
White bread	"	- " -	6.7	11.9	0.56	- " - No. 5
Potatoes	Jutland	- " -	2.7	4.7	0.57	C.2.5.3 No. 5
"	Islands	- " -	1.5	1.1	1.36	- " - No. 7
Cabbage	Denmark	- " -	2.2	2.5	0.88	- " - No. 1
Carrot	"	- " -	1.05	0.84	1.25	- " - No. 3
Apples	"	- " -	1.87	2.01	0.93	- " - No.11
Pork	"	- " -	21	28	0.75	C.3.4.2 No. 3
Beef	"	- " -	10.4	12.0	0.87	- " - No. 1
Eggs	"	- " -	1.37	2.80	0.49	C.3.6.2 No. 6
Total diet C	"	pCi ^{137}Cs (g K)$^{-1}$	2.7**	3.7	0.73	C.4.2.2 No. 1
" " P	"	- " -	3.0**	4.6	0.65	- " - No. 6

* (cf. note to Appendix C.1)

**Exclusive contribution of ^{137}Cs from Windscale.

APPENDIX D

$\underline{d_i}$:

Annual fallout rate in mCi ^{90}Sr km^{-2} y^{-1}.

Accumulated fallout by the end of the year (i) assuming effective half-lives of ^{90}Sr of 27.7 y. Unit: mCi ^{90}Sr km^{-2}.

$\underline{d_{i(May-Aug.)} \text{ and } d_{i(July-Aug.)}}$:

The fallout rates in the periods: May-Aug. and July-Aug., respectively. Unit: mCi ^{90}Sr km^{-2} $period^{-1}$.

The fallout rate (d_i) was based on precipitation data collected for all Denmark in the period 1962-1978 (cf. table 4.2.1[1]). Before 1962 the levels in the tables were estimated from the HASL data for New York (HASL Appendix 291, 1975)[29] considering that the mean ratio between ^{90}Sr fallout in Denmark and New York was 0.7 in the period 1962-1974.

The $d_{i(May-Aug.)}$ and $d_{i(July-Aug.)}$ values were also obtained from table 4.2.1[1] for the period 1962-1978. For the years 1959-1961 the values were calculated from data obtained from ^{90}Sr analysis of air (1959) and precipitation samples (1962 and 1961) collected at Risø. Before 1959, the values were estimated from the corresponding d_i values assuming that the ratios $d_{i(May-Aug.)}/d_i$ and $d_{i(July-Aug.)}/d_i$ were constant in time and equal to the means found for the period 1962-1974, which were 0.54 (1 S.D.: 0.09) and o.24 (1 S.D.: 0.06), respectively.

<u>APPENDIX D</u>. Fallout rates and accumulated fallout (mCi ^{90}Sr km^{-2}) in Denmark 1950-1979

	Denmark		Jutland		Islands	
	di	$Ai_{(27.7)}$	di	$Ai_{(27.7)}$	di	$Ai_{(27.7)}$
1950	0.021	0.020	0.022	0.021	0.020	0.020
1951	0.101	0.118	0.114	0.132	0.088	0.105
1952	0.198	0.309	0.224	0.347	0.172	0.270
1953	0.500	0.789	0.566	0.891	0.434	0.687
1954	1.901	2.623	2.152	2.967	1.650	2.279
1955	2.501	4.997	2.831	5.655	2.171	4.340
1956	3.101	7.898	3.510	8.939	2.692	6.858
1957	3.101	10.728	3.510	12.142	2.692	9.313
1958	4.302	14.658	4.869	16.591	3.734	12.725
1959	6.102	20.247	6.908	22.918	5.297	17.576
1960	1.140	20.859	1.291	23.610	0.990	18.107
1961	1.481	21.787	1.676	24.661	1.285	18.913
1962	7.428	28.493	7.976	31.830	6.880	25.155
1963	16.695	44.071	18.453	49.041	14.937	39.101
1964	10.412	53.136	11.685	59.225	9.139	47.048
1965	3.954	55.679	4.204	61.861	3.704	49.497
1966	2.145	56.395	2.166	62.445	2.124	50.345
1967	1.047	56.023	1.176	62.048	0.918	49.997
1968	1.403	56.006	1.568	62.045	1.237	49.968
1969	1.035	55.632	1.241	61.721	0.829	49.542
1970	1.647	55.863	1.993	62.140	1.301	49.586
1971	1.506	55.951	1.726	62.288	1.286	49.615
1972	0.435	54.993	0.457	61.194	0.413	48.792
1973	0.192	53.821	0.215	59.891	0.168	47.750
1974	0.710	53.183	0.779	59.171	0.643	47.197
1975	0.414	52.272	0.452	58.150	0.376	46.397
1976	0.103	51.082	0.116	56.826	0.090	45.339
1977	0.384	50.204	0.405	55.827	0.362	44.581
1978	0.463	49.426	0.538	54.985	0.388	43.867
1979	0.166	48.379	0.174	53.810	0.156	42.947

Denmark		Jutland		Islands	
di (May-Aug)	di (July-Aug)	di (May-Aug)	di (July-Aug)	di (May-Aug)	di (July-Aug)
0.01	0.01	0.01	0.01	0.01	0.01
0.05	0.02	0.06	0.03	0.05	0.02
0.11	0.05	0.12	0.05	0.09	0.04
0.27	0.12	0.31	0.14	0.23	0.10
1.03	0.46	1.16	0.52	0.89	0.40
1.35	0.60	1.53	0.68	1.17	0.52
1.67	0.74	1.90	0.84	1.45	0.65
1.67	0.74	1.90	0.84	1.45	0.65
2.32	1.03	2.63	1.17	2.02	0.90
2.50	0.68	2.76	0.75	2.24	0.61
0.47	0.31	0.52	0.34	0.42	0.28
0.66	0.47	0.73	0.52	0.59	0.42
4.223	1.857	4.566	2.052	3.880	1.662
9.965	5.629	10.753	5.932	9.177	5.327
6.235	2.568	7.170	2.910	5.299	2.226
2.029	0.850	2.094	0.852	1.964	0.848
1.049	0.418	0.984	0.496	1.114	0.340
0.367	0.141	0.380	0.134	0.354	0.148
0.848	0.426	0.910	0.460	0.786	0.392
0.614	0.276	0.723	0.319	0.505	0.233
0.908	0.547	1.076	0.632	0.740	0.462
0.992	0.405	1.154	0.516	0.830	0.294
0.253	0.084	0.262	0.084	0.244	0.084
0.075	0.033	0.093	0.039	0.057	0.027
0.421	0.190	0.463	0.219	0.378	0.162
0.159	0.075	0.179	0.091	0.157	0.060
0.032	0.010	0.032	0.011	0.032	0.009
0.178	0.107	0.164	0.085	0.190	0.129
0.232	0.096	0.275	0.098	0.188	0.093
0.086	0.030	0.087	0.031	0.084	0.029

REFERENCES

1) Risø Reports Nos. 1, 3, 9, 14, 23, 41, 63, 85, 107, 130, 154, 180, 201, 220, 245, 265, 291, 305, 323, 345, 361, 386, and 403 (1957-79).
2) R.G. Osmond, M.J. Owers, C. Healy, and A.P. Mead, The Determination of Radioactivity due to Caesium, Strontium, Barium and Cerium in Waters and Filters. AERE-R 2899 (1959).
3) F.J. Bryant, A. Morgan, and G.S. Spicer, The Determination of Radiostrontium in Biological Materials. AERE-R 3030 (1959).
4) John H. Harley, Manual of Standard Procedures. HASL-300 (1972).
5) A. Hald, private communication (1958).
6) J. Lippert, Low Level Counting. Risø Report No. 44 (1963).
7) P. Quittner, Nucl. Instr. and Methods 76, 115-124 (1969).
8) J. Lippert, Some Applications for Semiconductor Detectors in Health Physics. Proc. of the First International Congress of Radiation Protection, 271-277 (Pergamon Press, 1968).
9) Meteorologisk Institut, Ugeberetning om nedbør m.m. 1979.
10) S.L. Kupferman, V.T. Bowen, H.D. Livingstone and A. Aarkrog, Radioactive effluent from Windscale as a perturbation of the fallout tracer experiment in the North Atlantic Ocean. Submitted for publication in Earth Planet. Sci. Lett. (1979).
11) Folmer Dam and Agnes Elgström, Vore fødemidler (Svegårds Forlag, Sorø, 1968).
12) J. Vestergaard, Analysis of Variance with Unequal Numbers in Group. GIER System Library No. 211 (A/S Regnecentralen, Copenhagen, 1964).
13) Landbrugsstatistik 1975. Danmarks Statistik (Copenhagen, 1977).

14) Fortegnelse over samtlige mejerier og mejeriorganisationer i Danmark (Århus, 1972).

15) Statistisk årbog 1972 (Statistical Yearbook) (Copenhagen, 1972).

16) J. Lippert, Statdata, Risø-M-1780, June 1975.

17) S. Mattsson, R. Finck and M. Nilsson, Distribution of activation products from Barsebäck nuclear power plant (Sweden) in the marine environment. Temporal and spatial variations as established by seaweed. Environ. Pollut. Ser. B 1, 105-115 (1980).

18) Ebbe Kanneworff and Willy Nicolaysen, The "HAPS". A Frame-supported Bottom Corer. Ophelia 10:119-129 (Oct. 1973).

19) N.A. Talvite, Analyt. Chem. 43, 1827 (1971).

21) A. Aarkrog, Environmental Studies on Radioecological Sensitivity and Variability with Special Emphasis on the Fall-out Nuclides ^{90}Sr and ^{137}Cs. (To be published, 1980).

22) J. Brolund Larsen and S. Klausen, Foderplaner for malkekøer, 11. Ed. (Landhusholdningsselskabet, Copenhagen). 30 pp. (1969).

23) L. Bøtter-Jensen, A TLD environmental gamma monitoring system with automatic processing. (To be published 1979).

24) S.P. Nielsen, In situ measurements of environmental gamma radiation using a mobile Ge(Li) spectrometer system. Risø Report No. 367 (1977).

25) UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation. (New York) 725 pp. (1977).

26) P. Theodorson, Improved Tritium Counting through High Electrolytic Enrichment, Int. f. Appl. Radiat. Isotopes 25 (1974). 97-104 pp.

27) J.F. Cameron and B.R. Payne, Proc. of the 6. International Conference on Radiocarbon and Tritium. Dating, Pullmann, Washington, June 7-11, 1965, 454 pp. Conf. - 650652 mikro.

28) Statistisk årbog 1977 (Statistical Yearbook) (Copenhagen 1978).

29) HASL 291 Appendix, 1975.

30) N.A. Talvitie, Electrodeposition of Actinides for Alpha Spectrometric Determination. Analytical Chemistry, 44, pp. 280. February 1972.

31) S.P. Nielsen and L. Bøtter-Jensen, Intercomparison of Instruments for Measurements of Background Radiation. (To be published 1980).

32) A. Aarkrog, H. Dahlgaard, M. Edgren, E. Holm, S. Mattsson, Karen Nilsson, B. Persson, Upptag av naturlig och artificiell aktivitet i blåstång utanför Barsebäck och Ringhals kärnkraftverk. Det andet Nordiske Radioøkologiseminar Helsingør 8-10 maj 1979, Danmark (in Scandinavian).

33) H. Dahlgaard, Evaluation of bioindicators for monitoring radioactive pollution of estuarine and marine environments. Second International Symposium of Radioecology Cadarache, France, 19-22 June, 1979.

35) Sydkraft: Månadsrapport, and Vattenfall: Rapport över luft- och vätskeburna utsläpp, ... Ringhals. (Monthly reports to the Swedish authorities on discharges from Barsebäck and Ringhals, respectively) (in Swedish).

Sales distributors:
Jul. Gjellerup, Sølvgade 87,
DK-1307 Copenhagen K, Denmark

Available on exchange from:
Risø Library, Risø National Laboratory,
P. O. Box 49, DK-4000 Roskilde, Denmark

ISBN 87-550-0686-8
ISSN 0106-2840
ISSN 0106-407x